SMUD's Communicating Thermostat Usability Study

A simultaneous, multi-user, paired comparison test of communicating thermostats for task efficiency, preference, and perceived usefulness of advanced features

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Herter Energy
RESEARCH SOLUTIONS

Prepared by: Herter Energy Research Solutions, Inc.
2201 Francisco Drive, Suite 140-120
El Dorado Hills, California
www.HerterEnergy.com

Authors: Karen Herter, Ph.D.
Yevgeniya Okuneva, Statistician

Prepared for: Sacramento Municipal Utility District
Sacramento, California

Senior Program Manager: Lupe Jimenez

Project Manager: Melinda Brown

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EXECUTIVE SUMMARY

The goal of this study was to better understand the features that contribute to ease of use and preference for thermostats, and in particular, communicating thermostats. Data was collected during a 3-day lab study, during which 12 thermostats were each tested by between 26 and 28 participants, evenly distributed by age, education, income, home ownership, and gender.

Efficiency scores were calculated from time-on-task values derived from videos of each of the 326 thermostat tests. *Preference* scores were based on data collected in surveys indicating the preferred thermostat of each participant. Results of linear regression models that incorporated these efficiency and preference scores along with indicators for thermostat features and participant characteristics indicated the following:

Preference. Preference scores were significantly higher for thermostats with color displays and high overall feel and sound ratings. The three most preferred thermostats were the Carrier ComfortChoice Touch, Emerson Smart Energy, and Ecobee Smart Si.

Efficiency. Efficiency scores, based on time required to complete standard tasks, were significantly higher for thermostats with larger screens and higher ease of use ratings. The three most efficient thermostats were the Carrier ComfortChoice Touch, Honeywell FocusPro (one of two non-communicating units tested), and Emerson Smart Energy.

FIGURE 1. TOP SCORING COMMUNICATING THERMOSTATS

Carrier ComfortChoice Touch

Emerson Smart Energy

Ecobee Smart Si

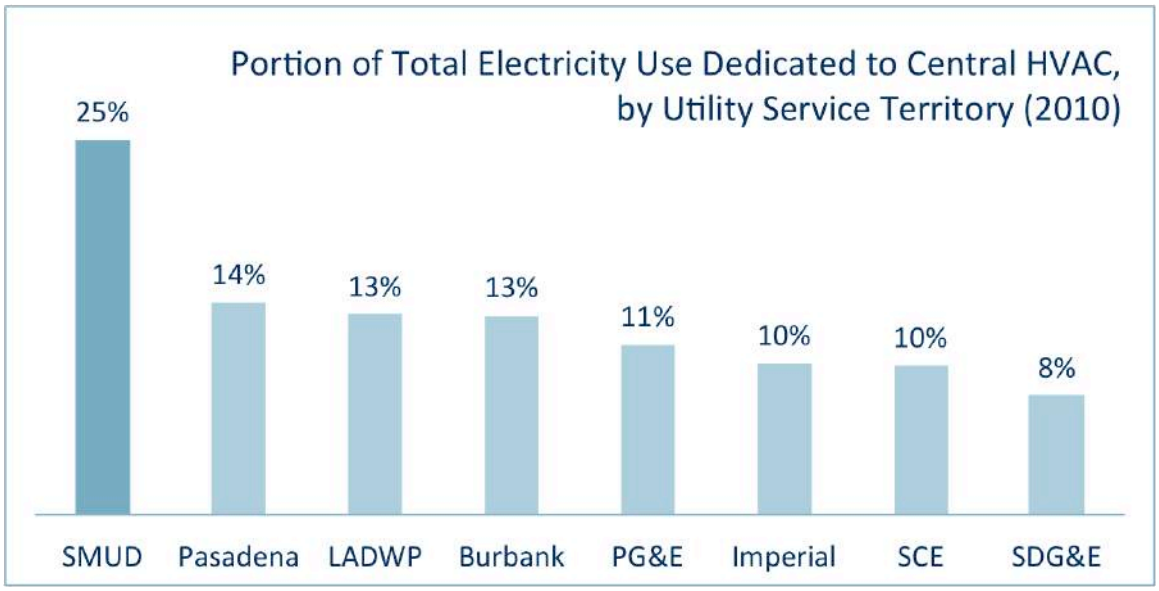
Based on these and other findings of this study, the research team recommends the following for future utility programs that involve thermostats:

1. Establish minimum threshold usability scores as a prerequisite for purchase.
2. Conduct usability tests for all thermostat models being considered for programs, to determine whether they meet the minimum threshold usability scores.
3. Provide extra training for renters and the elderly, who took significantly longer to complete common tasks than did younger participants and homeowners.

1 Background and Goals

The thermostat is an unassuming yet ubiquitous device that plays an increasingly large role in residential electricity use. In SMUD homes, thermostats control one-quarter of all electricity consumption – a fraction unmatched by any of the other major utilities in California (Figure 2). On the hottest summer days, residential air-conditioning is responsible for about one-third of SMUD's total 3,000-megawatt peak demand.

Figure 2. Residential HVAC electricity use in California



Source: California Energy Commission, 2009.

1.1 Thermostat Standards

Until recently, little has been done to take advantage of the energy savings opportunities inherent in thermostatic controls. Early efforts focused on the use of programmable setpoint schedules for reducing HVAC use when occupants were regularly away or asleep. Since the early 1980's, the California Energy Commission's Title 24 building standards have required that thermostats have four such programmable setpoints, designed for *Wake*, *Day*, *Evening*, and *Sleep* periods.

In 1995, the U.S. Energy Star program borrowed these programmable setpoint specifications for their voluntary thermostat certification program. About a decade later, however, Energy Star rescinded the thermostat certification program, citing several studies showing that the programming features were not being used properly, or at all, and that the promised savings had not materialized (Figure 3). Since then, Energy Star has been working with vendors and

researchers to devise a new set of specifications. The current proposed specifications require communications to allow "3rd party developers to enable access to the product's full range of communication and remote control capabilities." (Energy Star, 2012)[1]

FIGURE 3. PROGRAMMABLE THERMOSTAT STUDIES

Location	Organization	Year	Homes	Conclusions
Connecticut	Connecticut National Gas Corp.	1996	100	No significant change
Wisconsin	Energy Center of Wisconsin	1999	299	No significant change
Florida	Florida Solar Energy Center	2000	150	No savings, some increases
Northwest	Bonneville Power/PNNL	2001	150	No significant change
California	Southern California Edison	2004	N/A	Some savings, some increases

Source: Gunshinan 2007.

To date, the California Energy Commission has not followed Energy Star's lead in repealing the original 4-setpoint requirements; however, like Energy Star, California is pursuing a standards update that includes remote communications. The Commission's first attempt at setting a standard for "Programmable Communicating Thermostats" (or PCTs) was abruptly shelved in early 2008 when the media caught wind of plans to require emergency-based remote control of thermostats by utilities (New York Times 2008).

After removing the controversial requirement and renaming the devices *Occupant Controlled Smart Thermostats* (OCSTs) to emphasize the update, the Commission adopted OCSTs into California's 2013 building standards. (See Appendix B.) Communication and messaging must use standards-based protocols such as IP or ZigBee, OpenADR or Smart Energy Profile, and communications hardware may be built-in or removable.

Starting in 2014, OCSTs will become mandatory in nonresidential buildings, except where an energy management and control system (EMCS) fulfills the same functionality. At the same time, OCSTs will be a compliance option for residential new construction, as a trade-off for part of the solar-ready dedicated roof area requirement.

In summary, then, it appears that a transformation of thermostat functionality is imminent. The sudden shift towards communicating thermostat standards opens the potential for new communications-based functionality to be provided on a mass scale. The question remains, however, whether these new standards are an improvement on the previous standards, i.e. whether the new thermostats will be used in a way that actually helps customers use less energy. While it's too soon pass judgment on the far end of the communications path, we can say with some certainty that these new standards will not effect energy savings if customers

[1] See Appendix A for the current proposed Energy Star specification for thermostats.

don't like or can't figure out how to use the new thermostats. Our goal in this study, then, is to investigate and compare the usability and likeability of 10 of the newest thermostats on the market alongside two non-communicating thermostats commonly found in Sacramento homes.

1.2 An Overview of Usability Testing

The National Institute of Standards and Technology (NIST) defines usability as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." (NIST 2001)

Some of the basic elements of usability testing are as follows (Rubin and Chisnell 2008):

- Development of research questions rather than hypotheses
- Use of a representative sample of end users, which may or may not be randomly chosen
- Representation of the actual environment
- Observation of end users who either use or review a representation of the product
- Controlled interviewing and probing of the participants by the test facilitator
- Collection of quantitative and qualitative performance and preference measures
- Recommendation of improvements to the design of the product

This study made use of a specific implementation of usability test called a *comparison test*, where the purpose is to explicitly compare two or more products. The basic methodology involves side-by-side comparison of two or more different product designs. Performance and preference data are collected for each product and the results are compared. Comparison tests are typically used to establish which design is easier to use or learn, and to better understand the advantages and disadvantages of different designs (Rubin and Chisnell 2008).

The unique contribution of user testing is that it exposes what people actually *do*, as opposed to what they *say* – or say they will do. Paired-comparison testing was chosen for this study to elicit more honest critical feedback than would single-unit testing. With paired comparison testing, users are forced to choose one product over the other, and are given the opportunity to explain in more detail precisely what they liked about one product in relation to what was *not as good* about the other (Enerson 2012).

Although this study compares several instances of thermostats – twelve to be specific – the focus of the evaluation was to consider individual features, with the expectation that the best overall design may not be present, but rather a conceptual hybrid combination of the many feature options.

2 Study Overview

This document describes the implementation and evaluation of a simultaneous multi-user, multi-device comparison test of thermostats available for purchase in 2013. The testing was conducted to enable comparison of the short-term or "walk-up" usability of twelve different thermostats, meaning that participants were not provided with user manuals or coached in any way prior to their interaction with the thermostats.

2.1 Goals and Objectives

The primary goal of this study was to assess the features and functions of a variety of communicating thermostats to determine which characteristics might be recommended or required in specifications for thermostats promoted by or implemented for future programs at SMUD. The objectives of the study were to:

- Calculate and compare usability metrics for a sample of new thermostats
- Determine preferences for communicating thermostat features
- Identify specific design concerns, particularly for those thermostats involved in current or planned programs at SMUD

2.2 Research Questions

- How do performance efficiency metrics compare between products?
- How do satisfaction metrics compare between products?
- How do participants rate the advanced features they reviewed?
- What features are most helpful to users in completing common tasks?
- What flaws prevent users from completing common tasks?
- How do products rank in order of which is chosen most often as the favorite?

2.3 Approach

- Test 10 advanced and 2 standard thermostats under controlled lab conditions
    - Devise a list of common tasks for each participant to perform
    - Video record participant attempts to complete the task list
    - Conduct discussion sessions to gain further qualitative insights
- Review the video recording of tasks
    - Record done or not done for each task (success)
    - Record start and end times for each task (time-on-task)
- Establish baseline usability and satisfaction levels
    - Establish efficiency and satisfaction metrics
    - Calculate efficiency metrics for each task
    - Collect satisfaction metrics through surveys
    - Conduct statistical analysis of metrics

2.4 SCHEDULE

Month	Task
January	Develop research plan
	Procure equipment
February	Design and construct testing cubicles
	Draft scripts, surveys and other documentation
	Internal beta testing of process
March	Finalize testing process, scripts and documentation
	Perform trial run through of entire test with SMUD recruits
April	Recruit test participants
	Usability test
	Input survey data
May	Review video for time-on-task and success rates
	Calculate efficiency, satisfaction and overall usability ratings
	Draft Report
June	Final Report
	Final Presentation at SMUD

3 Study Approach

3.1 Overview

In the spring of 2013, SMUD commissioned a study to collect qualitative and quantitative data for use in comparing user interactions with and reactions to 2 common and 10 communicating thermostats. Each participant was asked to test two of the twelve thermostats to enable comparison of the *walk-up* usability of the thermostats. Participants were not provided with user manuals or coached in any way prior to the usability testing.

Test sessions involved an introductory discussion with the facilitator, the first thermostat test and survey, a discussion session, the second thermostat test and survey, another discussion session, and end. Interactions were video recorded as participants performed a realistic set of tasks using each thermostat. After each thermostat test, participants filled out a survey designed to collect ratings for thermostat usability, look, feel and sound. At the end of each thermostat test, a discussion session was held and recorded.

After three days of testing with participants, survey data, time on task measurements, and success rates were recorded and analyzed, indicating statistically significant differences in the ease of use metric and clear user preferences for certain thermostat features.

The following sections describe this approach and the data analysis results in greater detail.

3.2 Roles During Testing

Following are the roles of the people involved during the three days of lab testing.

Facility Staff

Facility staff members were present for the entirety of the testing to:

- Greet and direct participants as needed
- Provide assistance with internet connectivity issues
- Provide miscellaneous items that aided in testing (e.g. batteries, staplers, pens, etc.)
- Provide food and beverages

Facilitator

The facilitator was present for the entirety of each test session to:

- Provide an overview of the study and the purpose of usability testing to participants
- Indicate start and stop times for testing
- Conduct group discussion sessions
- Respond to non-technical requests for assistance

Participants

For each of the two thermostats tested, the participant's role was to:

- Attempt to complete a set of representative task scenarios as efficiently as possible
- Fill out a post-test questionnaire
- Participate in a discussion session to provide honest opinions regarding the usability and likability of the thermostats and supporting applications

Technical Support Staff

The technical support person was present for the entirety of each test session to:

- Monitor recording equipment
- Resolve technical problems with thermostats or other equipment

Principal Investigator

The principal investigator was present for the entirety of the testing to:

- Observe testing and take notes
- Direct facilitator and technical support staff as needed
- Address issues that could not be resolved by the technical support staff or facilitator
- Answer viewer questions

3.3 Participant Sample

A total of 180 residential SMUD customers were recruited for participation in the thermostat usability study based on a sample size power analysis showing the need for a minimum of 24 participant tests per thermostat. (See Appendix C). Using the recruitment script provided in Appendix D, about 15 participants were recruited for each of 12 cells defined by 6 age categories and 2 education categories. Of the 180 recruited participants, 163 attended the usability testing, as summarized in Table 1.

Table 1. Number of participants that attended the testing, by age and education

Age	Year of Birth	<4 years college	4+ years college	Total
18 – 28	*1985 – 1994*	16	12	**28**
28 – 38	*1975 – 1984*	12	13	**25**
38 – 48	*1965 – 1974*	14	11	**25**
48 – 58	*1955 – 1964*	14	17	**31**
58 – 68	*1945 – 1954*	15	13	**28**
68 +	*- 1944*	14	12	**26**
Totals		**85**	**78**	**163**

Demographic Distribution

An effort was made to assign participants to thermostat pairs in a way that ensured roughly even distribution of age, education, home ownership, gender, income, and confidence using a thermostat. Distributions for these variables are shown in Figure 4 through Figure 9.

Figure 4. Age distribution

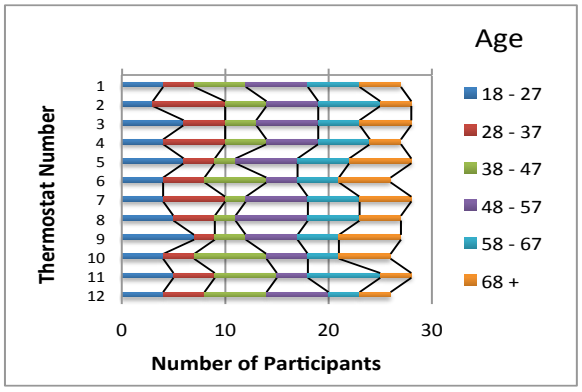


Figure 5. Education distribution

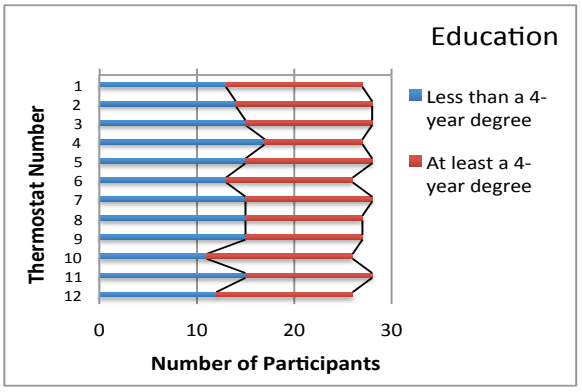


Figure 6. Income distribution

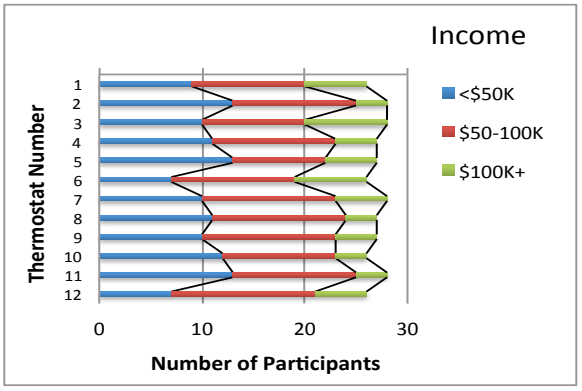


Figure 7. Home ownership distribution

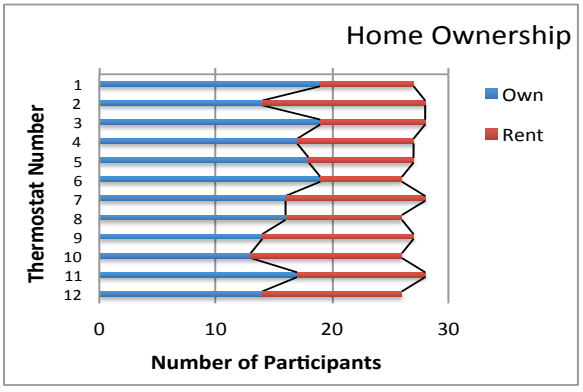


Figure 8. Gender distribution

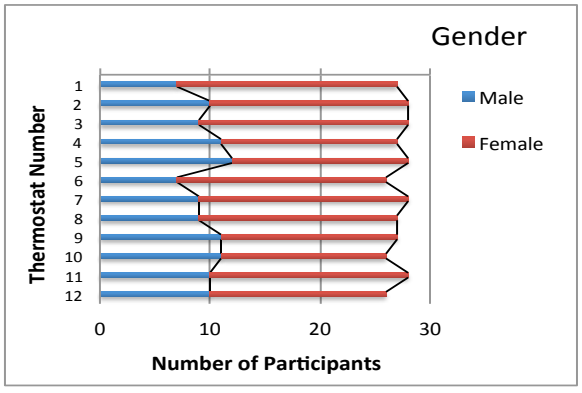
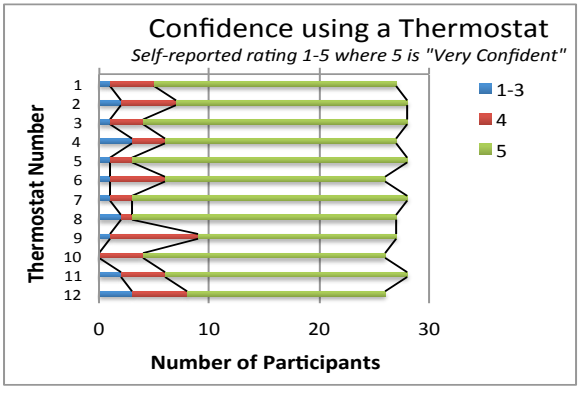


Figure 9. Confidence distribution

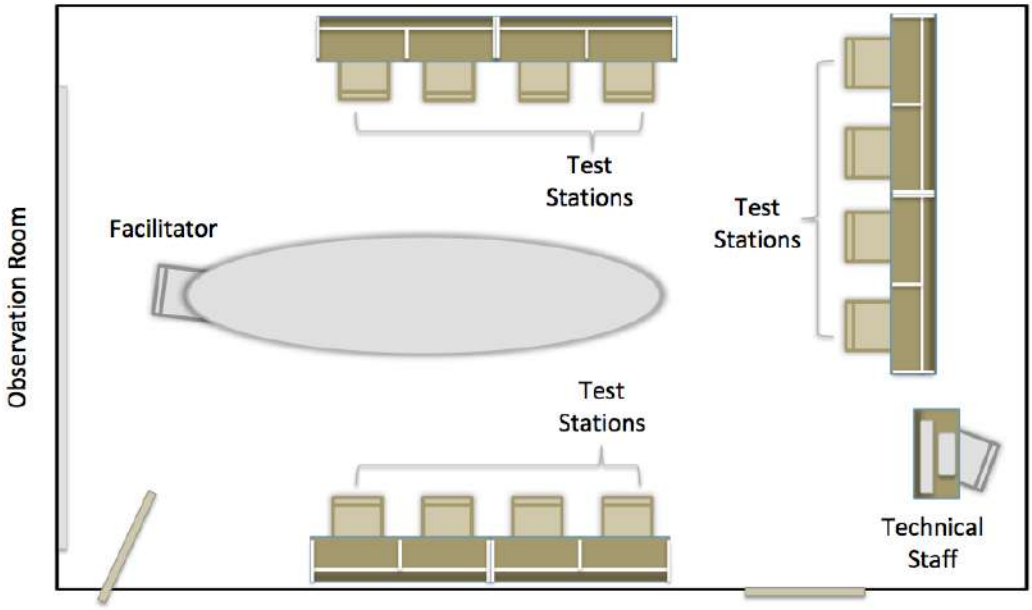


3.4 Test Lab and Equipment

The usability testing took place at a facility within the SMUD service territory. The test lab was equipped with multiple test stations affording each participant some privacy. A thermostat and its supporting applications were mounted in each cubicle, in view of the video camera. Video of participant faces was not recorded.

During testing, the facilitator and one technical support staff were seated in the same room as the participants, while observers monitored the sessions in the observation room.

Figure 10. Test room layout



Video Recording

Small cameras were affixed to each cubicle to record user interactions with the thermostats and supporting applications. One video was recorded for each of the 326 tests for later review. The facility also recorded all group discussions that took place at the large table in the center of the room, before, between, and after the testing of the thermostats at the test stations.

Web Access

Six of the thermostats tested required Internet connectivity – either directly or through gateways – for remote control by smartphone application or website. Both wired (Ethernet) and wireless (WiFi) Internet access was made available at the facility for use with these thermostats.

THERMOSTATS

A total of 12 thermostats were selected for testing as shown in Table 2. These units scored the highest priority ratings from a list of thermostats that were (a) currently used or planned for use at SMUD or (b) popular standard California Title 24 compliant thermostats readily available for sale at common retail outlets.

Of the twelve thermostats listed here, three were in use in SMUD field pilots in 2013: The Nest Learning Thermostat, the Ecofactor-Computime CTW218, and the Energate Pioneer.

TABLE 2. THERMOSTAT MODELS TESTED

ID	Device	Power	Zigbee Certified	Other	Remote Access	Image
1	Lux Smart Temp	battery	(non-communicating thermostat)			
2	Honeywell FocusPro	battery	(non-communicating thermostat)			
3	RCS TZ-45 (Trane 400BB)	24V 40VA		Zwave (*)	(*)	
4	Radio Thermostat CT30 (3M-50)	16V	SEP 1.0	WiFi, usnap	Web, App	
5	Nest Learning Thermostat	24V 40VA		WiFi	Web, App	
6	Ecofactor (Computime CTW218)	24V 40VA	SEP 1.0	IP gateway	Web, App	
7	Carrier ComfortChoice Touch	24V 40VA	SEP 1.1			
8	Ecobee Smart Si	12V 1.67A	SEP 1.1	WiFi	Web, App	
9	Energate Foundation FZ100	24V 450mA	SEP 1.1	IP gateway	Web, App	
10	Energate Pioneer Z100	24V 40VA	SEP 1.1	IP gateway	Web, App	
11	Cooper-Honeywell Utility Pro	24V 40VA	SEP 1.1	Pager	(*)	
12	Emerson Smart Energy	24V 40VA	SEP 1.1	(*)	(*)	

* Third-party gateway, Web, and/or App available but not tested

3.5 Thermostat Assignment

The 163 participants each evaluated 2 thermostats for a total of 326 individual tests.

All 66 potential thermostat pairs were tested at least once, and 126 of the 132 ordered pairs were tested at least once. To avoid order bias, each thermostat was the *first* unit tested in roughly half of the tests, and the *second* unit tested in the remaining tests.

Table 3 shows the final count of participants that tested each ordered pair of thermostats. The first unit tested is listed across the top as column headers, and the second thermostat tested is listed along the left side as row headers. For example, 2 participants tested thermostat 1 followed by thermostat 2, and 1 participant tested thermostat 2 followed by thermostat 1.

Table 3. Participant-thermostat assignments: first and second of two units tested

First Unit → / Second Unit ↓	1	2	3	4	5	6	7	8	9	10	11	12	Total
1		1	1	1	1	1	1	1	1	2	1	2	**13**
2	2		1	1	1	1	1	1	1	1	2	2	**14**
3	2	2		1	1	1	1	1	1	1	2	1	**14**
4	1	2	2		1	1	1	1	1	1	1	2	**14**
5	2	2	2	1		1	0	1	1	1	1	1	**13**
6	1	2	2	1	2		1		1	1	1	0	**12**
7	1	1	2	2	2	2		1	1	1	1	1	**15**
8	1	0	0	2	2	2	2		1	1	1	1	**13**
9	1	1	1	1	2	2	2	2		1	1	0	**14**
10	1	1	1	1	1	1	2	2	1		1	1	**13**
11	1	1	1	1	1	1	1	2	2	2		1	**14**
12	1	1	1	1	1	1	1	2	2	1	2		**14**
Total	**14**	**14**	**14**	**13**	**15**	**14**	**13**	**14**	**13**	**13**	**14**	**12**	**163**

3.6 Procedure

Before the testing process began, participants were required to review and sign nondisclosures and recording permissions (see Appendix E). Five sessions were held each day for three days. Each session accommodated up to twelve participants. Each session took 90 minutes, roughly following the schedule shown in Table 4.

Table 4. Agenda for each session

	Segment	Minutes
1	Introduction	15
2	Thermostat test #1	20
3	Discussion #1	15
4	Thermostat test #2	20
5	Discussion #2	15
6	Wrap up	5
	Total	90

Introduction

The facilitator briefed participants on the usability test procedure, including:

- the purpose of the study
- the importance of their involvement
- the facilitator's role
- the room configuration, recording systems, observers, etc.
- the testing protocol and agenda

Thermostat Testing

The facilitator briefed the participants on the testing process, stressing that the thermostats – not the participants – were being evaluated. The facilitator explained that the amount of time taken to complete each task was measured, and that exploratory behavior outside the task flow should not occur until after completion of all tasks. Participants were given 20 minutes to complete the entire task list and fill out the survey. (See Facilitator's Guide, Appendix F.)

Due to the range and extent of functionality provided in the thermostats, and the short time for which each participant was available, the tasks were designed to be the most common of available functions (Table 5, tasks 1-7). These common tasks were identical for all thermostats, with minor variations every other test to limit the need for lab staff to reset thermostats to default settings after each test. To accomplish this alternating test pattern, every thermostat was assigned one Booklet A and one Booklet B. After each test, during discussion sessions, lab

staff swapped from A to B or from B to A, and thermostat settings were adjusted for tasks that were not successfully completed.

Table 5. Alternating task lists A and B

Task	Task Booklet A	Task Booklet B
1	Identify the current indoor temperature	Identify the current indoor temperature
2	Set to cool. Identify the current target cooling temperature.	Set to cool. Identify the current target cooling temperature.
3	Change the current target cooling temperature to 79	Change the current target cooling temperature to 81
4	Identify the scheduled cooling temperature for Saturday at 8 am	Identify the scheduled cooling temperature for Saturday at 8 am
5	Set to heat. Identify the current target heating temperature.	Set to heat. Identify the current target heating temperature.
6	Change the current target heating temperature to 63	Change the current target heating temperature to 61
7	Identify the scheduled heating temperature for Saturday at 8 am	Identify the scheduled heating temperature for Saturday at 8 am
8	Advanced task 8A	Advanced task 8B
9	Advanced task 9A	Advanced task 9B

Where possible, each thermostat also had its own set of advanced tasks unique to that device. At the end of testing, the survey included questions designed to elicit preferences for these advanced features (Table 6, Table 7).

Table 6. Advanced Task 8

Thermostats	Task Booklet A	Task Booklet B
1,2,11	Set the day to Wednesday	Set the day to Saturday
3	Identify the Home energy use	Identify the Home energy use
7,12	Set the date to 1/11/13	Set the date to 2/12/12
4,5,6,8,9,10	Use the smartphone app to increase the target heating temperature by 3°F	Use the smartphone app to decrease the target heating temperature by 3°F

Table 7. Advanced Task 9

Thermostats	Task Booklet A	Task Booklet B
1,2,3,7,11,12	Set the time to 10:32 am	Set the time to 3:49 pm
4,5,6,8,9,10	Use the smartphone app to postpone heating until you get home	Use the smartphone app to postpone heating until you get home

The test commenced when users were told by the facilitator to begin. Participants were then directed to flip to the first card and begin task 1. The task ended when the participant marked that they did or did not complete the task on their task checklist. The next task began when they flipped over the next task card, and so on. Participants were directed to contact technical support staff immediately should any of the equipment fail to operate during testing.

Thermostat Surveys

Prior to beginning the test, each participant was provided a survey with their participant ID, pictures of their test thermostat, and survey questions regarding their experience with that particular thermostat. When they completed all tasks for one of the two thermostats, participants were directed to complete this survey. After the second thermostat test and survey, participants were given a third survey with questions about their preference for one of the two tested thermostats and the usefulness of advanced features.

The details of the thermostat's ease of use, look, feel and sound (Table 8) were rated on 10-point Likert scales. Other questions included whether the user would recommend the thermostat to a friend or neighbor, and the perceived value of the thermostat. An example of the full thermostat questionnaire is provided in Appendix G.

Table 8. Thermostat satisfaction questions

1	Rate EASE OF USE and UNDERSTANDING
a	Information on the screen
b	Buttons, dials and switches
c	Meanings of words and symbols
d	Menu navigation
e	Overall ease of use
2	Rate how the thermostat FEELS and SOUNDS
a	Buttons
b	Touchscreen
c	Dials
d	Switches
e	Overall feel and sound
3	Rate how the thermostat LOOKS
a	Layout of the screen and buttons
b	Size of the screen
c	Color(s)
d	Readability of the smallest text
e	Overall appearance of the thermostat

After the second thermostat test, an additional set of questions was provided to ascertain (1) which of the two thermostats was preferred, and (2) ratings for the desirability of a list of potential advanced features (Table 9).

TABLE 9. SURVEY QUESTIONS TO RATE PERCEIVED USEFULNESS OF ADVANCED FEATURES

7	Do you think you would find the following features useful on a thermostat in your home?
A	**Auto-Schedule**: The thermostat programs your temperature preferences for you, based on your adjustments in the first week or two.
B	**Auto-Away**: The thermostat automatically adjusts the temperature when it senses your home is unoccupied.
C	**HVAC Energy Display**: The thermostat displays the amount of electricity used by your central heating and cooling system.
D	**Home Energy Display**: The thermostat displays the amount of energy used by your home.
E	**Efficiency Indicator**: The thermostat indicates when you adjust it to an energy efficient temperature setting.
F	**Time to Temperature**: The thermostat displays how long it will take to reach the target temperature.
G	**Online Account**: You can use a computer to adjust your thermostat settings remotely
h	**Smart phone app**: You can use a smart phone to adjust your thermostat settings remotely
i	**Color display**: The main display has more than 2 colors.
J	**Touchscreen**: The main screen is also an input device.
K	**Outdoor temperature**: The thermostat can display the outdoor temperature
l	**Price response**: The thermostat automatically adjusts settings based on your input and the price of electricity
m	**Precool**: The thermostat automatically cools your home before a high-priced peak period
n	**Proximity**: Your thermostat knows your location and automatically switches between home and away settings
o	**Parental Controls**: The thermostat allows changes to settings only after a password is provided

Group Discussions

At the end of each thermostat test and survey, a short focus group discussion took place. Lab staff used this time to check each thermostat for correct task completion and to reset the thermostats to the default initial test state for the next session as needed.

Conducting a group discussion between the two thermostat evaluations ran the risk of providing some information to participants about the thermostat tested in round two. Despite this possibility, we chose to include the discussion between the two tests for the following reasons:

- With or without the discussion between the two tests, there would be increased familiarity with the process and tasks in the second test.
- Each thermostat was tested first and second an equal number of times, so the bias inherent in the second test was evenly distributed across thermostats.
- Richer, more relevant feedback was made possible by having two discussions; i.e. the experience with the first unit may have been lost if the two tests were contiguous.
- Lab staff needed that time for logistic purposes – checking to see that the thermostats were ready for the second test.

4 Data, Analysis, and Results

For this comparison study, qualitative data, satisfaction ratings, task efficiency metrics, and preference metrics were collected for use in comparing between products and features.

4.1 Pros and Cons of tested Thermostats

Following is a list of pros and cons for each thermostat pulled from the verbatim comments left on the post-test thermostat surveys. Note that these comments, in aggregate, form the basis for the variables considered in the regression modeling described later in this paper.

Table 10. Summary of participant comments for each thermostat

ID	Thermostat	Pros (from survey comments)	Cons (from survey comments)
1	Lux Smart Temp	· Easy to use and program · Good labels · Basic instructions provided · Good button feel	· Small screen and print · Small, loud dial and switches · Dim screen · Looks old
2	Honeywell FocusPro	· Easy to navigate · Button feel and labels · Screen layout and size · Nice, simple look	· Confusing schedule · Bad brightness and contrast · Buttons stick · No confirmation of input
3	RCS TZ-45 (Trane 400BB)	· Easy to use · Easy to read, good font size · Blue backlight is nice · Simple, intuitive layout · Energy use data is nice	· Button click too loud · Too plain · Too many different screens
4	Radio Thermostat CT30 (3M-50)	· Large touchscreen · Backlight is nice · Clear print · Smartphone App is good	· Hard to navigate · Backlight goes off too quickly · Too much info on the screen · Confusing icons/symbols · Touchscreen not sensitive
5	Nest Learning Thermostat	· Smartphone App is good · Modern, hi-tech, advanced · Looks and feels good · Dial is nice, simple to use · Would be easier with practice	· Screen too small · Confusing menu · Hard to get started
6	Ecofactor-Computime CTW218	· Backlight is nice · Can use with smartphone, PC	· Buttons feel cheap, too loud · Odd shapes and layout of buttons · Ugly, too big, bulky, looks cheap · Inconsistent interfaces for app, thermostat, and computer

(continued from the previous page)

ID	Thermostat	Pros (from survey comments)	Cons (from survey comments)
7	Carrier Comfort Choice Touch	· Touchscreen, colors are good · Easy to use and program · Large, well lit, easy to read · Buttons feel and sound nice · Looks nice	· Thermostat too big · Mushy rubber buttons · Plastic frame too big, seems cheap
8	Ecobee Smart Si	· Sleek, colorful, modern · Bright, easy to read · Button feel and sound · Home button useful · Easy to use and navigate	· Small display · App is difficult to use · Confusing, cluttered menu · No Help button · Symbols and labels need explaining
9	Energate Foundation FZ100	· Button size, shape, and feel · Energy saver, pricing nice · Easy to navigate · Easy to read · Good information on screen	· Too many buttons · Small screen · Multi-function of some buttons · Boring colors · Not modern looking
10	Energate Pioneer Z100	· Easy to navigate · Buttons feel and sound nice · Backlight is nice · Smartphone App	· Button layout · Hard to navigate menu · Multi-function of some buttons · Small print · Not bright enough
11	Cooper-Honeywell Utility Pro	· Large touchscreen is nice · Easy to use · Good information on display	· Thermostat too big · Buttons and text too small · Backlight goes off too quickly · Screen hard to read: poor contrast · Touchscreen not responsive · No confirmation sound
12	Emerson Smart Energy	· Large text, screen; easy to read · Easy to use and navigate · Bright, blue backlight · Good button size, feel, layout · Buttons are quiet · Solid, sturdy, modern, clean	· Hold is confusing · Middle button should be lit · Screen could be bigger · Difficult to set schedule

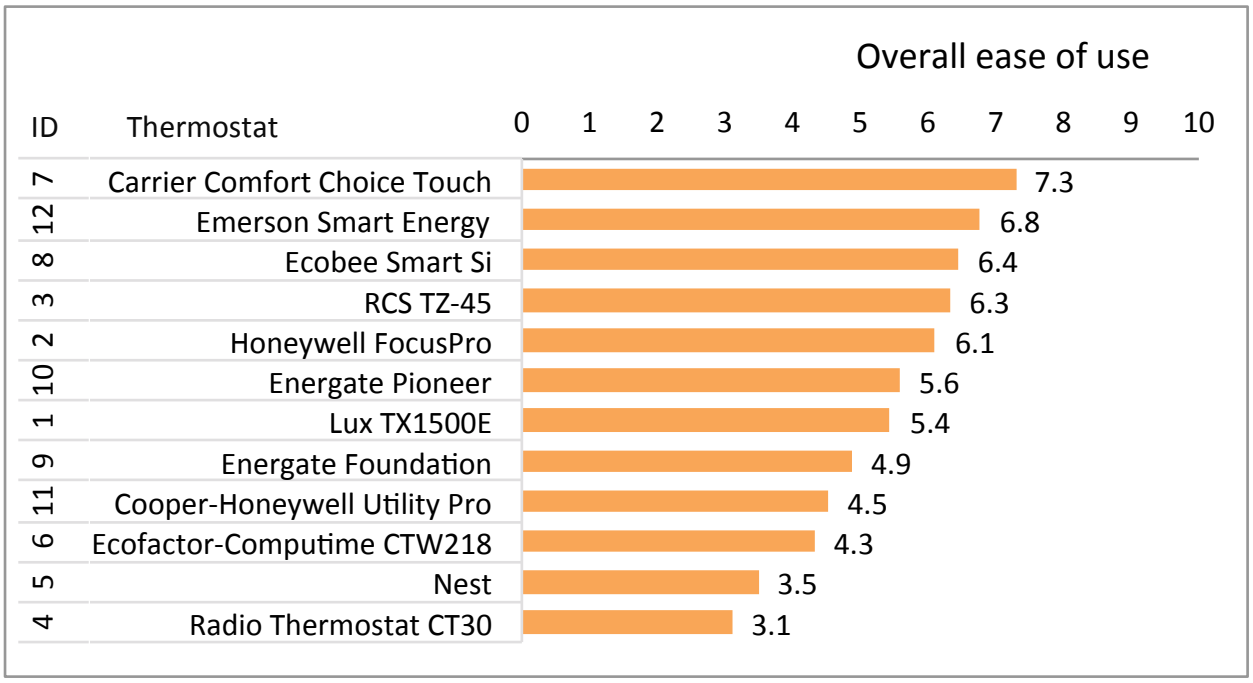
4.2 Feature Ratings for tested Thermostats

After testing each thermostat, participants filled out surveys as described in Section 3.6. This section provides the average thermostat ratings for the overall ease of use, feel and sound, and appearance as rated by participants in these surveys.

Ease of Use

Figure 11 ranks the 12 thermostats tested for this study by participant scores for "Overall Ease of Use" (Table 8, question 1e). Of the twelve, the Carrier ComfortChoice Touch garnered the highest average rating, statistically outperforming the bottom four rated thermostats: the Radio Thermostat CT30, Nest, Ecofactor/Computime CTW218, and Cooper/Honeywell Utility Pro. Other thermostats that were highly rated for ease of use include the Emerson Smart Energy, the Ecobee Smart Si, the RCS TZ-45, and the Honeywell FocusPro.

Figure 11. Usability ratings for all thermostats tested



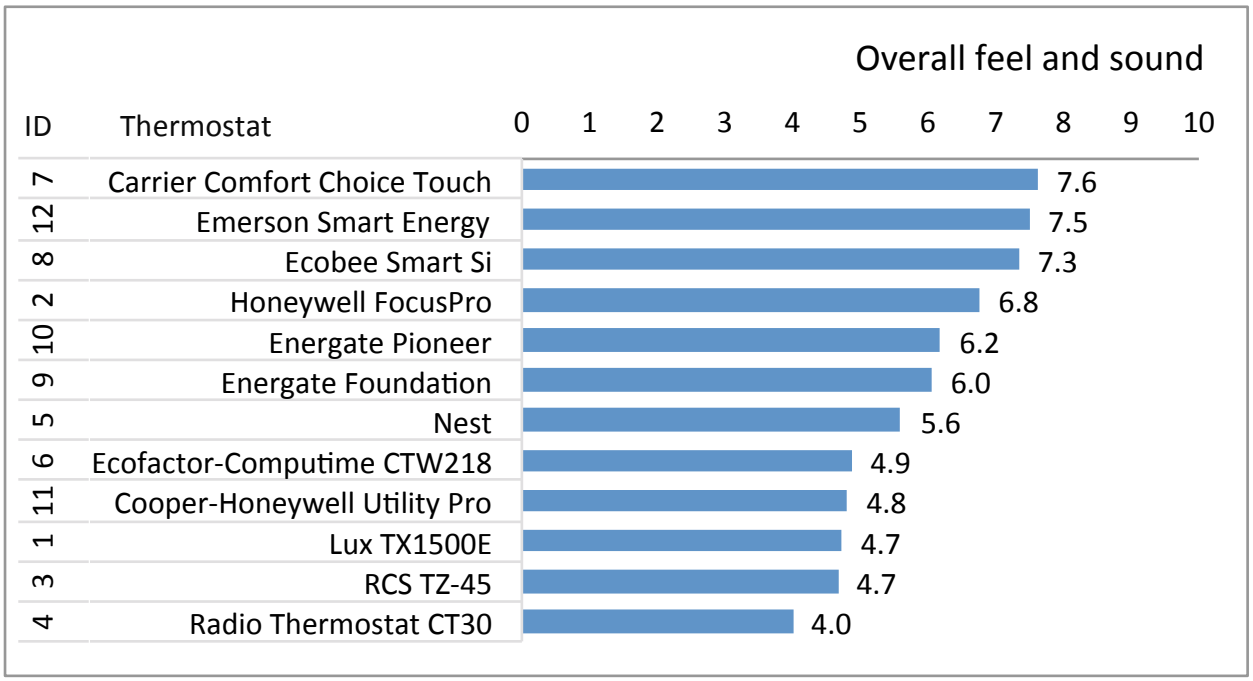
Statistical significance bounds: ± 2.5 (α=0.01)

The Energate Pioneer, which is being used in two SMUD pilots in summer 2013, ranked sixth in this category. The Ecofactor and Nest thermostats, also being used in 2013 pilots, ranked a disappointing 10th and 11th out of 12 in the Ease of Use category.

Feel and Sound

Figure 12 shows that the Carrier ComfortChoice Touch also took first place in "Feel and Sound" (Table 8, question 2e) – the category that turns out to be the most significant in predicting participant preferences, as will be seen in the following pages. In this category, the Carrier statistically outperformed the bottom five rated thermostats: the Radio Thermostat, RCS TZ-45, Lux TX1500E, Cooper/Honewell Utility Pro, and Ecofactor/Computime CTW218. Other thermostats that were highly rated for feel and sound include the Emerson Smart Energy, the Ecobee Smart Si, and the Honeywell FocusPro.

Figure 12. Feel and Sound ratings for all thermostats tested



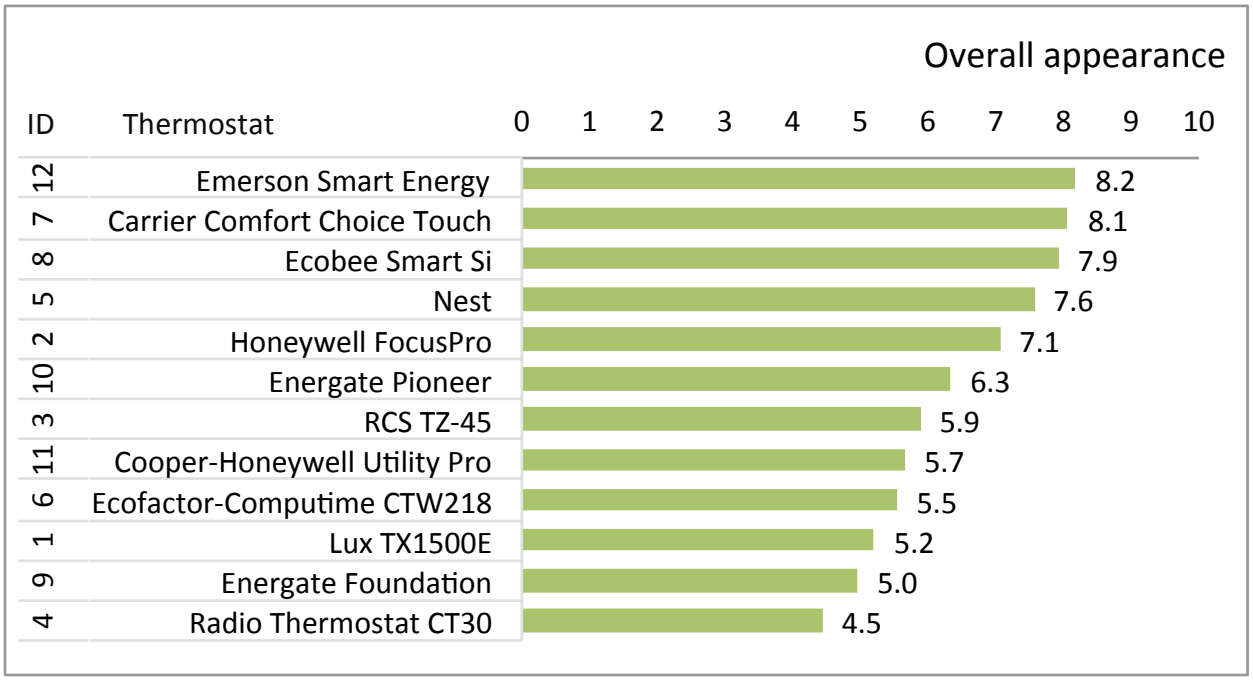
Statistical significance bounds: ± 2.6 (α=0.01)

The Energate Pioneer, which is being used in two SMUD pilots in summer 2013, ranked fifth in this category. The Nest and Ecofactor thermostats, also being used in 2013 pilots, ranked 7th and 8th out of 12 in the Feel and Sound category.

Appearance

Figure 13 ranks the thermostats tested for this study by participant scores for "Overall Appearance" (Table 8, question 3e). The Emerson Smart Energy took first place, statistically outperforming the bottom five rated thermostats: the Radio Thermostat, Energate, Lux, Ecofactor, and Cooper. Other thermostats highly rated for Appearance include the Carrier ComfortChoice Touch, the Ecobee Smart Si, the Nest Learning Thermostat, and the Honeywell FocusPro.

Figure 13. Appearance ratings for all thermostats tested



Statistical significance bounds: ± 2.4 (α=0.01)

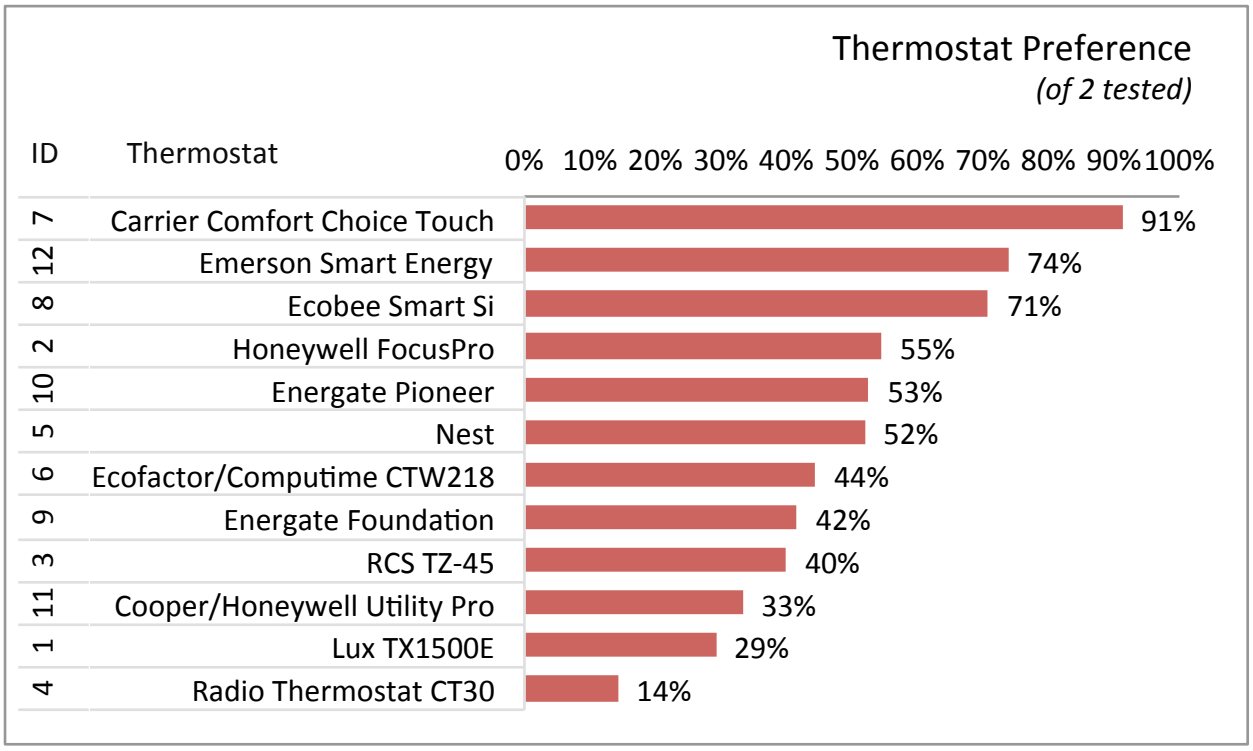
Of the thermostats used in SMUD field pilots in 2013, the Nest thermostat ranked 4th, the Energate Pioneer ranked 6th, and the Ecofactor ranked 9th out of 12 in the Appearance category.

4.3 Preferences for Tested Thermostats

In the survey provided after the second thermostat test, participants were asked to choose the thermostat they would purchase given the choice of the two units they had tested. More than 90% of participants that tested the Carrier ComfortChoice Touch chose it as their preferred thermostat (Figure 14). Of the 22 participants that chose the Carrier, 18 participants cited among their reasons: the ease of use (11 participants), the touchscreen (5 participants), the appearance (4 participants), the clarity and size of the font (4 participants), the color display (2 participants), and advanced features (2 participants).

Also popular were the Emerson Smart Energy and the Ecobee Smart Si, while the Radio Thermosats CT30, Lux TX1500E, and Cooper/Honeywell Utility Pro ranked in the bottom three. The Energate Pioneer and Nest, which are being used in SMUD pilots in summer 2013, were the fifth and sixth most preferred thermostats, respectively.

Figure 14. Preference scores for all thermostats tested



Statistical significance bounds: ± 60% (α=0.01)

4.4 Task Efficiency scores for tested thermostats

All 326 video recordings of the usability tests were reviewed to capture Time-on-task and Success measures for each thermostat, participant, and completed task. These measures were then used to calculate the individual and average Task Efficiency metric for each thermostat.

For all tasks marked "Done" on the task checklist, the task start time was recorded at the moment the numbered task card became visible by the camera, and the end time was recorded as the participant marked their checklist. In a few cases, participants did not complete the task on the first try, marked their checklist Not Done, then returned to and completed the same task later in the session. In these cases, the two times were added together to obtain the total Time-on-task metric.

Successful completion of the task was also determined using the video recording. Tasks successfully completed received a Success score of 1, while those that were not successfully completed received a Success score of 0, even if the participant marked that task on their checklist "Done."

Together, the Time-on-task and Success metrics were used to calculate the *Task Efficiency* metric, defined on a scale from 0% to 100%, such that 0% indicates that the task could not be completed at all, and 100% indicates successful completion in no time (Eq. 1). A similar metric is described in Perry et al., 2011.

$$\text{Task Efficiency} = 2s / (1+e^{t}) \qquad (1)$$

Where

- s = Success = {0 for failed tasks; 1 for completed tasks)
- t = Time-on-Task = time to complete the task, in minutes.

Figure 15. Task Efficiency metric ranges from 100% to 0%

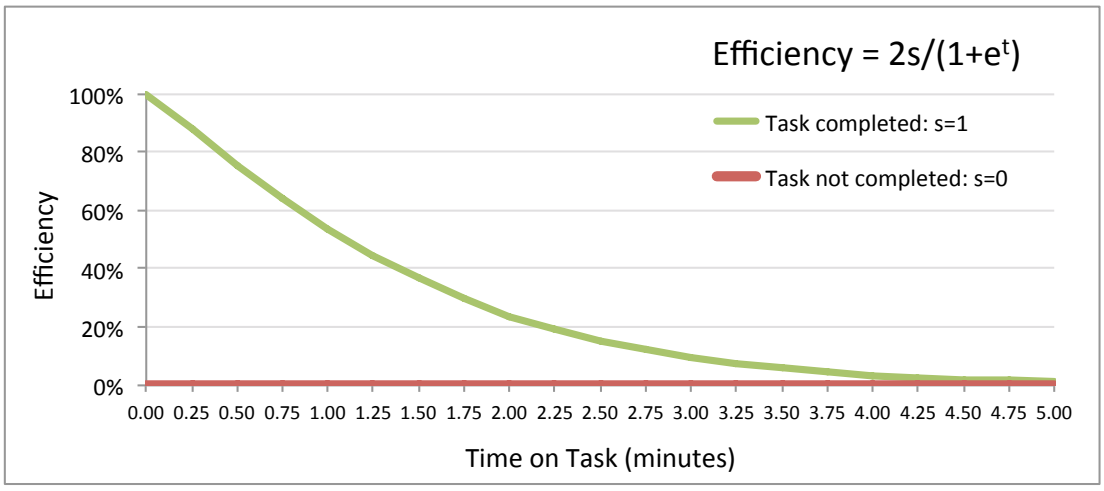
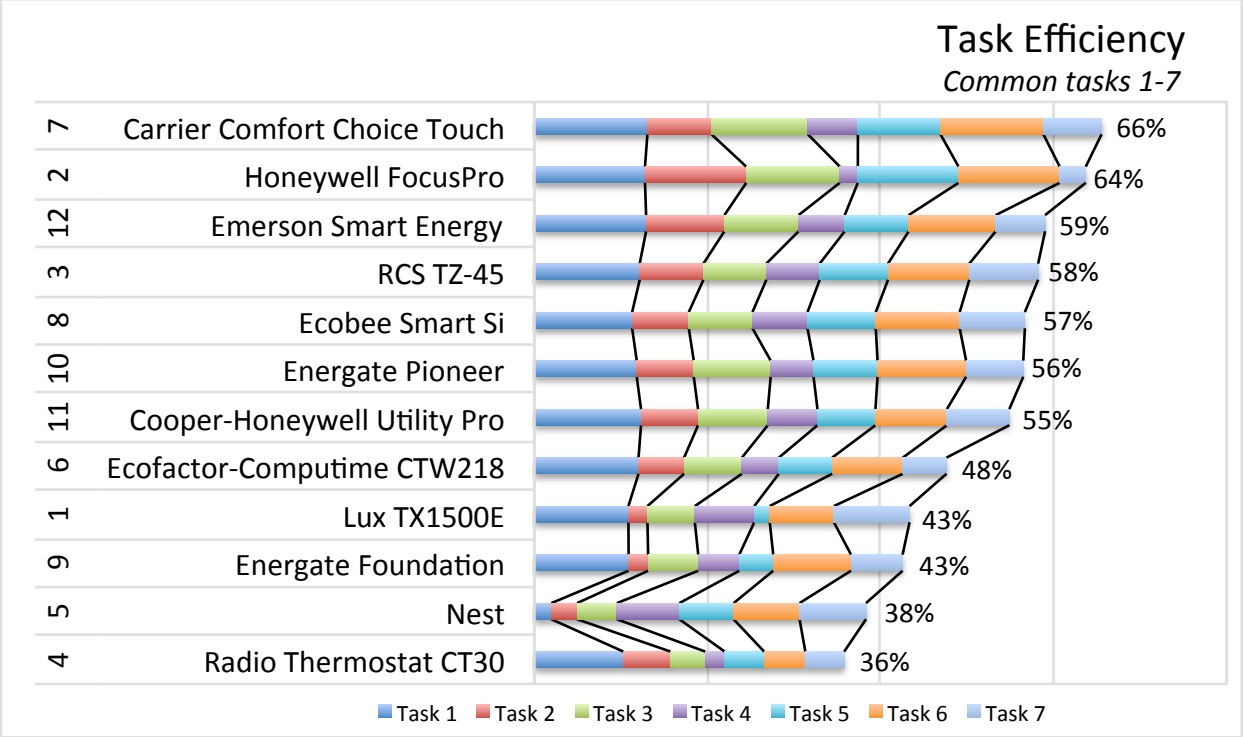


Figure 16 ranks the twelve thermostats tested in this study by final efficiency scores calculated using Equation 1. Proportional contributions from each task are shown as different colored sections. With a maximum score of 100%, the top ranked thermostat is the Carrier ComfortChoice Touch at 66%, followed closely by the Honeywell FocusPro at 64%. The Energate Pioneer, currently in the field for two SMUD pilots, scored sixth. Scoring below 50% were the Radio Thermostat, Nest, Energate Foundation, Lux, and Ecofactor/Computime thermostats.

FIGURE 16. TASK EFFICIENCY SCORES FOR ALL THERMOSTATS TESTED



Statistical significance bounds: ± 12% (α=0.01)

Visually striking in Figure 16 is the unusually low score for Task 1 of the Nest, which asked for the current indoor temperature. This low efficiency score is mainly the result of participants mistaking the large number in the center of the Nest for the current indoor temperature, when in fact it represented the target temperature. The actual current indoor temperature value is revealed only when the face of the thermostat is pushed or turned, and then it is displayed as a much smaller number located on the dial's perimeter. Another contributing factor was that participants were not provided with instructions, and it took a long time for many of them to realize that the entire face of the Nest had to be pushed and turned for input. In fact, more than half of participants that tested the Nest were unable to come to this realization during the 20-minute test period.

4.5 Regression Models for Preference and Efficiency

To investigate the effects of thermostat features and participant characteristics on participant thermostat Preference and task Efficiency, two ordinary linear regression models were implemented. The first model regressed the Preference scores shown in Figure 14 on the fifteen variables shown in Table 11, selected to represent the full set of features and participant characteristics while avoiding multicollinearity. The second model regressed the Efficiency scores shown in Figure 16 on the same fifteen variables (Table 11).

Table 11. Regression model variables

Variable Type	Description	Data type
Participant Characteristics	Household income less than $50,000	Boolean
	Household income $50,000-$100,000	Boolean
	Age (18+)	Continuous
	Education: more or less than a 4-year college degree	Boolean
	Gender	Boolean
	Homeowner or renter	Boolean
	Self-rated confidence using a smartphone	Continuous
	Self-rated confidence using a thermostat	Continuous
Thermostat Features	Remote control via SmartPhone App	Boolean
	Overall appearance rating (survey question 3e)	Continuous
	Overall ease of use rating (survey question 1e)	Continuous
	Overall feel and sound rating (survey question 2e)	Continuous
	Color display screen (more than 2 colors)	Boolean
	Screen size in square inches	Continuous
	Touchscreen	Boolean

Preference Model Results

Based on the Preference model output, none of the 8 participant characteristics shown in Table 11 had a significant impact on thermostat preference. More important in participant preferences were the thermostat features. Of the 7 thermostat features included in the model, the following two significantly increased the likelihood that a participant would choose one thermostat over another:

1. Good overall feel and sound (p=0.002)
2. Color display (p=0.008)

For the full Preference model output, see Appendix H.

Efficiency Model Results

Based on the Efficiency model output, 2 of the 7 thermostat features from Table 11 were associated with significantly higher task efficiency scores:

1. Higher ratings for ease of use (p<0.0001)
2. Larger screens (p=0.002)

Efficiency was also influenced by 2 of the 8 participant characteristics from Table 11. In particular, this study showed significantly lower efficiency scores for:

1. Older participants (p<0.0001)
2. Renters (p=0.003)

Notably absent from this list are variables for income, education, and gender. In fact, of the 15 variables included in the regression model, these had the lowest effect on Task Efficiency, having p-values greater than 0.60 in all cases. Other factors that were found to be unrelated to Task Efficiency scores were self-rated confidence using thermostats and smart phones.

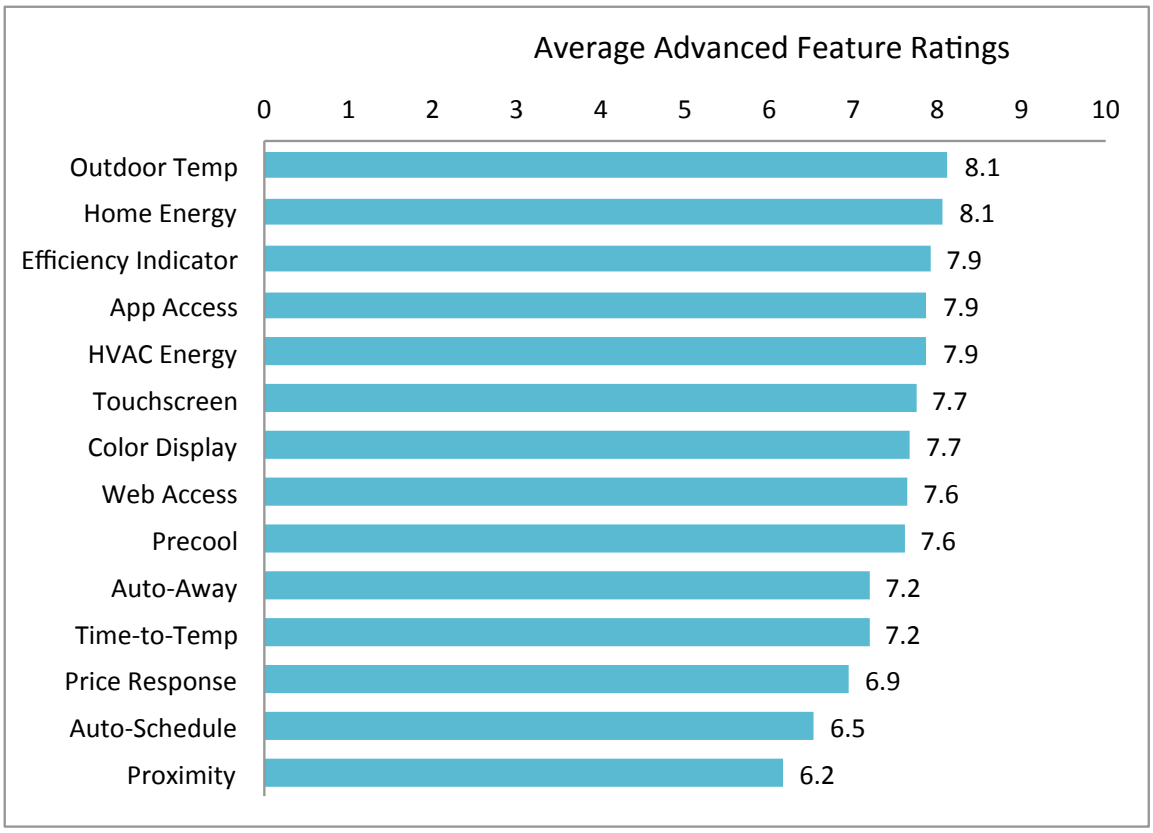
For the full Efficiency model output, see Appendix H.

4.6 Advanced Feature Ratings

The second survey, completed after the completion of both thermostat tests, presented participants with the question: "Do you think you would find the following features useful on a thermostat in your home?" Possible responses ranged from 1, Not at all, to 10, Definitely. (See Table 9 for the full list of advanced features, or Appendix G for the full survey.)

Overall, the ability to see Outdoor temperature and real-time Home Energy use on the thermostat garnered the highest ratings – however, efficiency indicators, smartphone access, HVAC energy data, touchscreens, color displays, web access, precooling functionality, auto-away, time-to-temp, and price response functionality scored statistically similar ratings. Only Auto-schedule and proximity features scored statistically lower than the top rated features.

FIGURE 17. PERCEIVED USEFULNESS OF 15 ADVANCED FEATURES

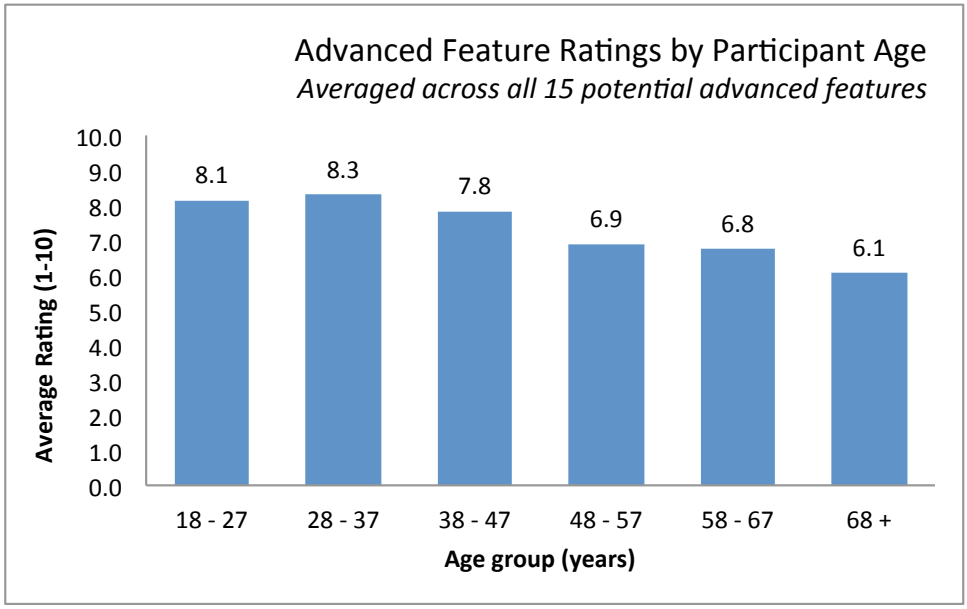


Statistical significance bounds: ± 1.3 (α=0.01)

Advanced Feature Preferences by Age

These advanced feature ratings become somewhat more interesting when considered alongside the age of the participant. In general, younger users were much more likely to consider any of the advanced features useful, as indicated by the average ratings provided in Figure 18.

Figure 18. Average ratings across all 15 advanced features, by age

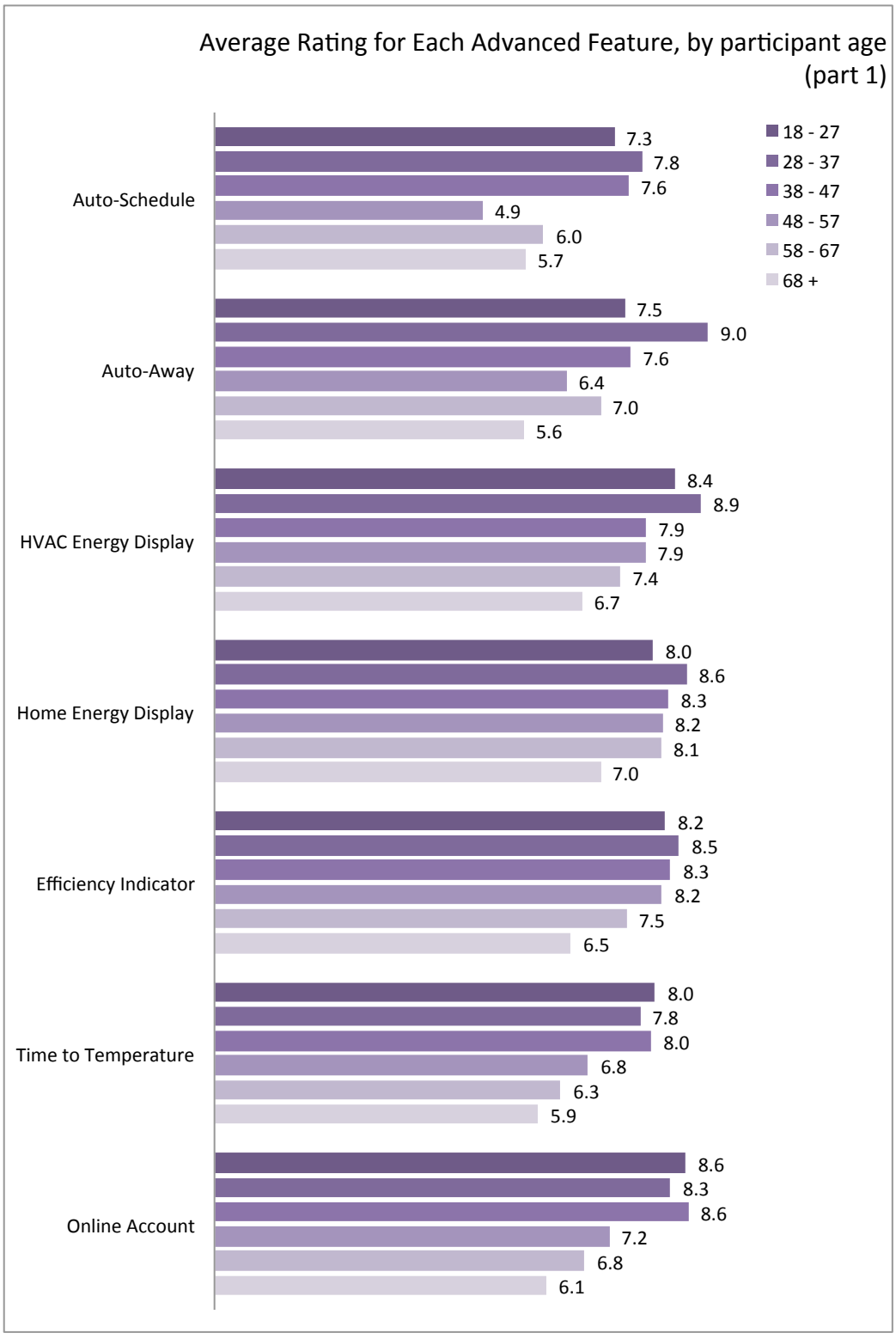


On a feature-by-feature basis (Figure 19), the ratings are surprisingly consistent, with younger participants generally giving higher ratings and older participants generally giving lower ratings.

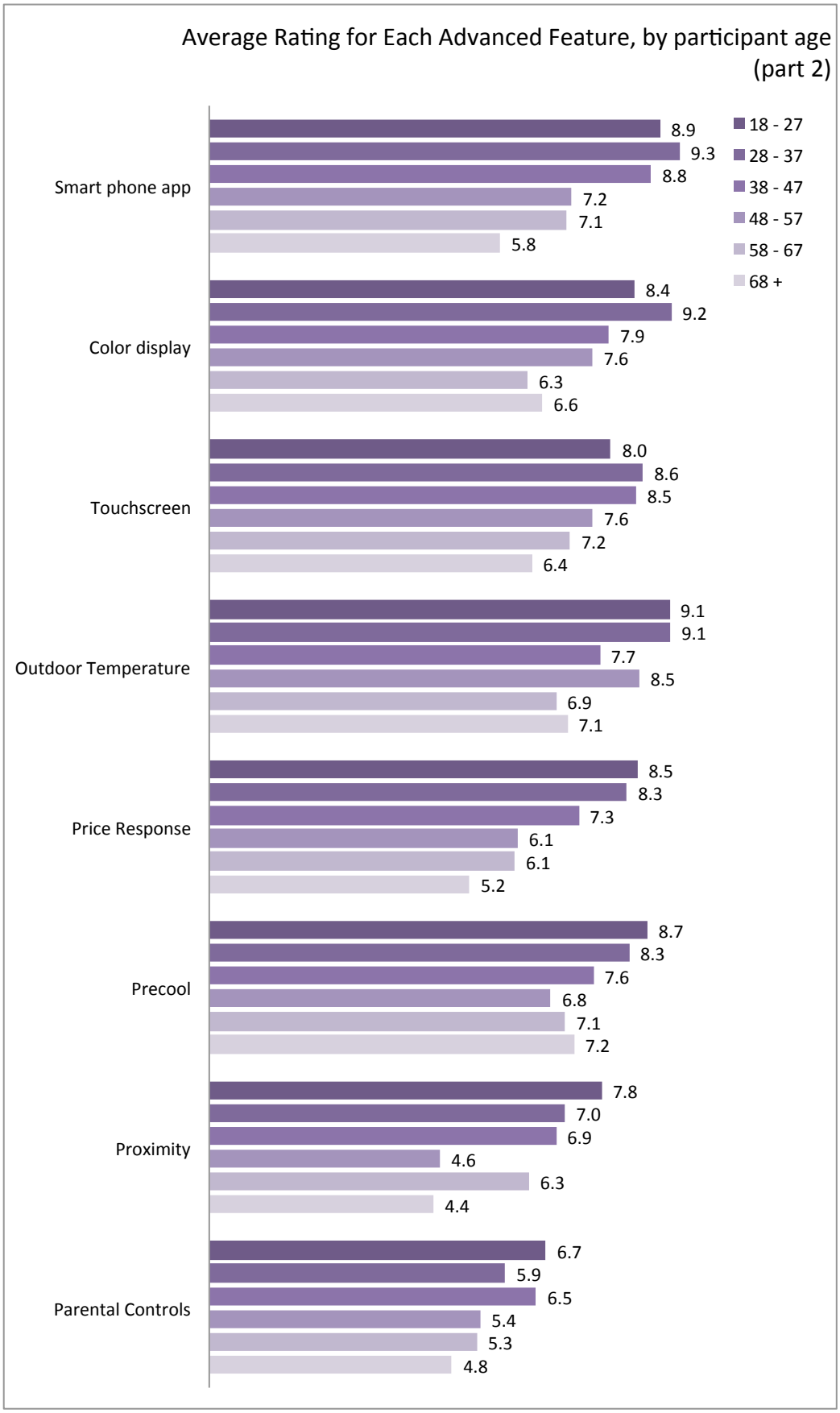
Note that the Home Energy Display not only has one of the highest average ratings, but is also the most universally appreciated, being the only advanced feature with average ratings at or above 7.0 in every age category.

At the other end of the spectrum, Auto-Away functionality and Smartphone applications had the largest spread in ratings, with the 28 to 37 years olds being the most enthusiastic, and the participants 68 years and older being the most uninterested.

FIGURE 19. AVERAGE RATING FOR EACH ADVANCED FEATURE, BY PARTICIPANT AGE



(Figure 19 is continued on the next page.)


Average Rating for Each Advanced Feature, by participant age (part 2)
18 - 27
28 - 37
38 - 47
48 - 57
58 - 67
68 +
Smart phone app
8.9
9.3
8.8
7.2
7.1
5.8
Color display
8.4
9.2
7.9
7.6
6.3
6.6
Touchscreen
8.0
8.6
8.5
7.6
7.2
6.4
Outdoor Temperature
9.1
9.1
7.7
8.5
6.9
7.1
Price Response
8.5
8.3
7.3
6.1
6.1
5.2
Precool
8.7
8.3
7.6
6.8
7.1
7.2
Proximity
7.8
7.0
6.9
4.6
6.3
4.4
Parental Controls
6.7
5.9
6.5
5.4
5.3
4.8

Other Advanced Feature Requests

Beyond the 15 advanced features we asked participants to rate, some users used the discussion sessions to suggest a few additional thermostat features they would like. These included:

- Ability to enlarge the font or zoom in
- Ability to integrate with other devices, e.g. whole house fans
- Ability to set a budget for heating/cooling and have thermostat automatically adjust
- Customer programmable screen color options
- Decorative housing skins
- Display bill balance on thermostat
- Help videos and demos
- Motion sensing to turn backlighting on and off automatically
- Simple climate control dials, with red for hot and blue for cold
- Sound options – type, tone and volume
- Voice control
- Wireless unit that can be placed anywhere in the home

5 CONCLUSIONS

The goal of this study was to link thermostat features and participant characteristics with Task Efficiency and Thermostat Preference. During the three-day lab study, 163 participants performed identical tasks on 2 thermostats, filled out surveys, and participated in focus group discussion sessions. Each of 12 thermostats was tested by between 26 and 28 participants, roughly evenly distributed by age, education, income, home ownership, and gender.

Surveys collected user ratings for test thermostats' ease of use, feel and sound, and appearance, along with participant preference for one of the two thermostats tested and ratings for 15 potential advanced features. Videos of individual thermostat tests were used to determine time-on-task for each task.

Time-on-task values were used to calculate an Efficiency metric for each task and thermostat on a scale from 0 to 1. Thermostat Preference was calculated as the percentage of participants that chose that thermostat from the two they tested. Average Efficiency and Preference scores were used as the dependent variables in separate linear regression models that included 15 thermostat features as independent variables.

The main findings of this study are as follows.

Preference scores were significantly higher for thermostats with:

1. Good overall feel and sound (p=0.002)
2. Color displays (p=0.008)

Preference scores were similar across participants of differing age, gender, education, income, home ownership, and technology IQ.

Efficiency scores were significantly higher for thermostats with:

1. Higher ratings for ease of use (p<0.0001)
2. Larger screens (p=0.002)

Efficiency was also influenced by the characteristics of the user. In particular, this study showed significantly lower efficiency scores for:

1. Older users (p<0.0001)
2. Renters (p=0.003)

The remainder of this section provides a discussion of these findings by participant characteristics, by feature, and by thermostat.

5.1 Results by Participant Characteristics

During the recruitment process, participants were asked to provide information about their age, education level, income, and confidence using a variety of technologies. Of these, only those variables describing age and home ownership were associated with significant impacts.

Age

Participants in this study were recruited to fill six ten-year age groups: 18-27, 28-37, 38-47, 48-57, 58-67, and 68+. Regression analysis indicated that higher ages were strongly associated with lower Task Efficiency scores, but had no influence on thermostat Preference. Age did, however, influence preferences for specific advanced features, with older participants generally being much less interested in advanced features than their younger counterparts (see Figure 18, Figure 19).

Home ownership

Home ownership was a significant predictor for Task Efficiency, with renters scoring significantly lower than homeowners. Since efficiency was not related to income or education levels, a possible explanation for the effect of home ownership is that renters have been exposed to older, cheaper, and less user-friendly thermostats than have homeowners. Given fewer positive experiences navigating thermostats, they might be more likely to use them as on-off switches rather than attempting to master a new device each time they move.

Gender, Education, and Income

Variables for gender, education and household income were not significant in the regression model.

Confidence with Technology

Participants' self-reported confidence with smartphones and thermostats had no significant impact on Task Efficiency or Thermostat Preference.

5.2 Results by Thermostat Feature

Ease of Use

As expected, the Ease of Use rating was a significant predictor of Task Efficiency, but not a significant predictor of Preference. Thus, the physical features of look, feel and sound tend to be the priority when consumers are choosing a thermostat. This finding underscores the importance of usability testing, since decisions based on physical features are unlikely to produce the most usable or user-friendly units, and this could be detrimental to program goals in the longer term. Unfortunately, ease-of-use ratings are not easily come by, requiring substantial unit testing and some analytical effort.

Feel and Sound

The rating for the "overall feel and sound" of the thermostat was by far the strongest predictor of Preference. Individual ratings for feel and sound of buttons, dials, switches and touchscreens were ultimately dropped from the models due to missing data for thermostats without these input devices and multicollinearity with the "overall feel and sound" rating.

Appearance

In the discussion sessions and survey comments, many participants commented on the appearance of the thermostats. Some disliked thermostats that are taller than they are wide, while others were more concerned with overall size or how far it stuck out from the wall. Many said they preferred those that look more modern, and pointed out those in the room that appeared too old-fashioned for their taste. Although overall appearance rating was not a significant predictor of Preference or Efficiency, the individual appearance variables screen size and color display did significantly affect Efficiency and Preference, respectively. Ratings for layout of the screen and buttons, and readability of the smallest text were not significant.

Screen size

A larger screen size was associated with significantly improved Task Efficiency scores – but somewhat unexpectedly, not with improved Preference scores. Screen sizes of the 12 thermostats included in this study ranged from 2.4 square inches for the highly preferred Ecobee Smart Si with a Preference score of 71%, to 10.0 square inches for the Cooper/Honeywell Utility Pro, which had Preference score of just 33%. As indicated by the results of the regression analysis, the color display and feel and sound of the Smart Si were more important to user Preference than was the larger screen size of the Cooper-Honeywell Utility Pro.

Color display

Color display was associated with significantly higher scores for Thermostat Preference. This feature was also frequently mentioned in the survey comments and discussion sessions as being a preferred feature. In the advanced feature ratings, color display ranked seventh, but was in a statistical dead-heat with the most popular of the advanced features.

Touchscreen

Somewhat surprisingly, thermostats with touchscreens scored significantly lower on Task Efficiency and Thermostat Preference, despite a fairly high rating for touchscreens in the advanced features survey. Based on participant comments, this outcome is likely related to the low preference ratings for the touchscreen thermostats with mono displays – the Radio Thermostat (black on gray) and the Cooper/Honeywell Utility Pro (black on green), both of which scored in the bottom three preferred thermostats studied.

Number of physical buttons

The number of buttons was not a significant predictor of Efficiency or Preference. In the discussion session and survey comments, comments on the number of buttons were very few, suggesting that this feature is not particularly important to customers. As further evidence, one could look at the thermostats studied to find that the two most popular thermostats had very different numbers of buttons. The most Preferred thermostat, the Carrier ComfortChoice Touch, had just 3 buttons, while the second most preferred thermostat, the Emerson Smart Energy, had the most of any of the units at 10. A likely confounding factor in this variable is that touchscreen "buttons" could not be counted as buttons because the number of these changed depending on the available menu options. Because of these confounding factors, this variable was omitted in the final model.

SmartPhone App

The existence of a smartphone app did not improve or degrade the Efficiency or Preference scores for this study. Many participants, both in the surveys and in the discussion sessions, explicitly mentioned the smartphone app as a positive feature, however, there were also those who said they would not use a smartphone app at all.

In reviewing survey data for advanced features (Figure 19), one can see that there is a large discrepancy between the younger and older participants: on average, the 28 to 37 year-old group rated the smartphone app a 9.3 out of 10 possible points, but the 68 and over group rated it just 5.8 out of 10. In fact, of all the advanced features, the smartphone app was the one with the largest age discrepancy.

5.3 Results by Thermostat

Table 12 lists the pros and cons for each of the 12 thermostats, focusing only on the features that contribute significantly to the Efficiency and/or Preference for each thermostat. For a summary of customer comments without regard to statistical significance, see Table 10.

Table 12. Summary of statistically significant pros and cons of tested thermostats

ID	Device	Image	Preference Rank	Efficiency Rank	Pros	Cons
7	Carrier Comfort Choice Touch		1	1	Large screen Good feel/sound Color display Easy to use	
12	Emerson Smart Energy		2	3	Good feel/sound Large screen Easy to use	Mono display
8	Ecobee Smart Si		3	5	Good feel/sound Color display Easy to use	Small screen
2	Honeywell FocusPro		4	2	Good feel/sound Large screen	Mono display
10	Energate Pioneer Z100		5	6	Good feel/sound	Mono display
5	Nest Learning Thermostat		6	11	Good feel/sound Color display	Small screen Not easy to use
6	Ecofactor-Computime CTW218		7	8		Bad feel/sound Mono display Not easy to use
9	Energate Foundation FZ100		8	10	Good feel/sound	Small screen Mono display
3	RCS TZ-45 (Trane 400BB)		9	4	Easy to use	Bad feel/sound Mono display
11	Cooper-Honeywell Utility Pro		10	7	Large screen	Bad feel/sound Mono display Not easy to use
1	Lux Smart Temp		11	9		Bad feel/sound Small screen Mono display
4	Radio Thermostat CT30 (3M-50)		12	12		Bad feel/sound Mono display Not easy to use

1. Lux Smart Temp

One of two standard thermostats tested in this study, the Lux was considered somewhat old-fashioned and hard to use relative to the other thermostats tested.

Ease of Use

Participants who tested the Lux Smart Temp thermostat generally found the labels on the unit and main screen useful and easy to understand, but in many cases too small to read. Many were confused by the battery indicator at the bottom left of the screen, and at least as many could not figure out the meaning of the small round H button (which was for humidity).

Several participants complained that there were simply too many different input mechanisms, which made input busy and cumbersome. Many also complained about the small size of the dial and switches, which were difficult for many to operate.

Overall, participants found the navigation "a little confusing" and "not self explanatory." In particular, some participants were not clear if and when their input had been set and stored in the thermostat.

Feel and Sound

Participants had few nice things to say about the feel and sound of the Lux, although some mentioned that they liked the feel of the Lux's solid manual input mechanisms over the feel of a touchscreen. The feel of the "tiny" switches and dial were again at issue, and many found the clicks of the dial too "noisy" and in one case "violent." Many participants found the Lux "average," but a few thought it felt "flimsy" or "could see it breaking easily."

REPORT CARD

Ease of Use	54%
Feel and Sound	47%
Appearance	52%
Task Efficiency	43%
Preference	29%
Overall Grade	C-

Appearance

Many participants liked the size and simplicity of the Lux, and also the drop-down door that not only hid most of the input mechanisms, but also opened to present basic operation instructions. A few found the detailed information "too cluttered" and the screen too small, dim, and hard to read. A handful of participants thought this unit looked cheap and outdated.

2. Honeywell FocusPro

Although the Focus Pro tested was not a communicating thermostat, participants were impressed by the simple operation and quality look and feel of the unit.

Ease of Use

Most participants liked the simplicity of the Honeywell Focus Pro, found the screen information easy to read and understand, and liked the buttons at the bottom that changed purpose as the menu was navigated. Many or most had difficulty setting the schedule. Some mentioned the limitation of setting the time by minutes rather than hours and minutes. Many were uncertain about whether their settings had been saved, and wanted confirmation from the device that indicated they had completed the task correctly. Participants who were familiar with the "hold" function liked the small HOLD button to the right of the up-down arrows, but many were uncertain of its purpose.

Feel and Sound

Most of the participants liked the "soft" feel of the buttons, which had a rubber eraser feel, but one did not like the "mushy" feeling. Others found them stiff, hard to push, and sticky. Some liked the quiet operation, while others wished the unit made some noise to confirm setting changes.

REPORT CARD

Ease of Use	61%
Feel and Sound	68%
Appearance	71%
Task Efficiency	64%
Preference	55%
Overall Grade	B+

Appearance

The appearance of the Focus Pro received high ratings from participants, who liked the large, clear screen, and simple layout. Participants found most text large enough to read, but the smallest text was too small for many. Some participants found the screen too dim, and a few complained that the indoor temp should be in the center of the screen instead of the time.

3. RCS TZ-45 (TRANE 400BB)

Participants liked the energy display available on the RCS TZ-45, but universally disliked the loud noise made by the up-down buttons.

EASE OF USE

Participants gave the TZ-45 high ratings for ease of use, citing easy to understand menu text and straightforward, self-explanatory hierarchical navigation. However, many found the pairings of menu items with the four buttons at the bottom unintuitive. For example, a few indicated that the Select and Done buttons should be reversed, so the Select button would be on the left and the Done button on the right. Others found it confusing that the word "Hold" appeared twice on the main screen.

Several participants highlighted the Energy menu, which showed instantaneous kW and daily kWh information, saying it was a feature they would like to have.

REPORT CARD

Ease of Use	63%
Feel and Sound	47%
Appearance	59%
Efficiency	58%
Preference	40%
Overall Grade	C+

FEEL AND SOUND

Nearly universal and all-consuming of participant comments about feel and sound were complaints about the loud clicking sound and stiffness of the up-down buttons on the TZ-45, using phrases like "hard to push," "annoying" and "loud."

APPEARANCE

Participants generally liked the blue screen color of the TZ-45 – a sentiment that was echoed for other thermostats with blue backlit screens. Participants also liked the clean, simple layout and easy to read text, but a few wished the smallest text were a bit bigger. Most found the size of the screen and housing just about right, although some wished the screen was bigger and the housing smaller. Negative comments tended to focus on the unit being too plain. One disliked the color of the housing, likening it to the color of "a white sock that has been worn by a construction worker."

4. Radio Thermostat CT30 (3M-50)

A low-quality touchscreen and difficult navigation contributed to the poor showing of this low-cost communicating thermostat, but many testers liked the accompanying smartphone app.

Ease of Use

Participants found the CT30 thermostat difficult to navigate, being unable to find what they needed, unclear on what the symbols meant, and unsure whether to press the touchscreen or one of several buttons available on the face and side of the unit. Of the 27 participants who tested this unit, just 3 chose it over the other unit tested. When asked why they wouldn't recommend it to a friend, more than half expressed concerns over its ease of use, calling it "difficult," "confusing," "time consuming," and "complicated." Several preferred the accompanying smartphone app.

Feel and Sound

Participants had few compliments on the look and feel of the CT30, with most leaving this section blank on their survey or mentioning that they liked the app. One or two liked that it had a touchscreen, but most found the touchscreen on the CT30 was hard to push, not responsive, and of low quality.

The buttons on the side were hard to push and "sticky feeling" to some, and too loud to others. Participants also disliked the way the unit felt, calling it "plasticky" and cheap.

Appearance

Participants liked the large current indoor temperature set at the middle of the screen, but several thought that there was too much information on the screen, some of it unintelligible. Some liked the overall high tech look of the unit, while others thought it looked old and cheap. Several liked that it had a backlight, but complained that it was not bright enough and went off too quickly, making one feel "like you had to race before the light went out."

REPORT CARD

Ease of Use	31%
Feel and Sound	40%
Appearance	45%
Efficiency	36%
Preference	14%
Overall Grade	D-

5. Nest Learning Thermostat

Before testing, the Nest Learning Thermostat was the only unit that generated unsolicited attention and interest. Many participants were intrigued by its sleek, round, retro look and blue glow – so much so that some even protested that they did not get the opportunity to test it. Those who tested the Nest, however, were ambivalent. Negative comments collected in the surveys focused almost exclusively on the difficultly figuring out the input mechanism.

Ease of Use

Most participants mistook the large number in the center of the thermostat for the current indoor temperature, when in fact it represented the current target temperature. In addition, more than half of the participants that tested the Nest – 16 of 28 – were unable to figure out the turn and push input mechanism at all or until the very end, such that most participants that tested the Nest were unable to complete more than one or two tasks. As a result of these two issues, the Nest garnered a very low 38% Task Efficiency score, placing it in the number 11 position for Efficiency.

Feel and Sound

The cold glass, metallic disc, and iPhone like clicks scored highly on the "feel and sound" category.

Appearance

Participants loved the round color display and metallic housing of Nest, but some found the screen and text a little small. Most participants mistook the target temperature displayed in large font in the center for the current temperature.

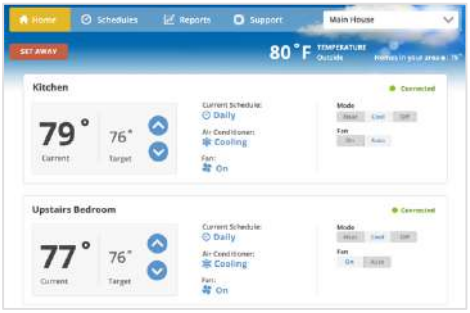
REPORT CARD	
Ease of Use	35%
Feel and Sound	56%
Appearance	76%
Task Efficiency	38%
Preference	52%
Overall Grade	C+

6. Ecofactor-Computime CTW218

Most participants liked the app that came with the Ecofactor-Computime CTW218, but disliked the button layout and navigation of the thermostat unit.

Ease of Use

A major issue with the CTW218 was that the confusion between the large buttons imprinted with symbols for up and down and the small round button at the bottom of the unit. Many participants had trouble determining, in one participants words, "whether to use the up down arrow or the side to side arrow," which in turn made the navigation of menus "puzzling." One of the customers inadvertently pressed the up and down buttons at the same time, initiating a lockout function, and then was unable to complete any further tasks.



Another common complaint was that the thermostat interface was not consistent with the smartphone app or the computer interface. In essence, this required that the participant learn multiple interfaces for the same appliance, which in some cases was "totally confusing."

Not specifically mentioned in the comments, but seen in the video, was an issue that involved an unintuitive and complicated series of button pushes to navigate menus and change menu item values. This caused a reasonable amount of confusion during menu navigation for many participants.

Appearance

Many participants disliked the button layout and considered the large silver up and down buttons on the right side of the unit unattractive. A few participants did not recognize the large silver up-down buttons as buttons at all until well into the timed testing period. One participant complained that three different button sizes and shapes were too many.

REPORT CARD	
Ease of Use	43%
Feel and Sound	49%
Appearance	55%
Task Efficiency	48%
Preference	44%
Overall Grade	C

7. Carrier ComfortChoice Touch

The words "user friendly and "easy" were used over and over in describing the Carrier ComfortChoice Touch thermostat, and testers seemed enamored with the variety of advanced features available.

Ease of Use

Most participants found the Touch exceptionally easy to navigate. One participant summed it up by saying "you know when and what has been set with confidence, no guess work involved." Many praised the large, clearly labeled buttons, and some found the Home button particularly useful for navigation. A few thought the unit should have left and right buttons in addition to the up and down buttons, while others thought the up-down buttons were unnecessary and could be incorporated into the touchscreen.

Some of the advanced features testers said they liked include: the eheat feature, the lockout feature, the clean screen feature, the screensaver option, the features for cost and cost tier notification, and the sound on-off feature.

REPORT CARD

Ease of Use	73%
Feel and Sound	76%
Appearance	81%
Task Efficiency	66%
Preference	91%
Overall Grade	A+

Feel and Sound

Nearly all participants liked the feel of the touchscreen, but many found the buttons rubbery, sticky, stiff, or "like marshmallow" – and preferred the feel of the responsive touchscreen, which was perceived to be of high quality.

Some participants discovered the setting to turn the button sound on or off, so some participants experienced the Touch with button sound and some experienced it without. Feedback on this was mixed, with some who had the sound wished it was completely silent or at least had volume control, while those who had no sound complained that there was no auditory feedback.

Appearance

Most participants liked the large, well-lit, easy-to-read color screen, intuitive layout, and simple, high tech look of the Touch. A few thought the unit was too large or protruded too far from the wall. Several commented that they liked the blue color of the screen.

8. Ecobee Smart Si

If the Nest was the most impressive thermostat before participants had the chance to test it, the Ecobee Smart Si was the most impressive of the units after testing. Participants that tested it called it a "great product hands down," the "easiest one I've ever used," and "ideal for any home."

Ease of Use

While most participants found the Smart Si easy to use, some – in particular those who said they were not skilled with smartphones – had more trouble navigating the smartphone-like interface. One participant was opposed to having to navigate a menu "just to turn the heating or cooling on/off."

Although the availability of the accompanying smartphone app was a favorite feature, many of the participants that interacted with the app found it less intuitive than the thermostat interface. In several instances, participants accidentally logged out of the smartphone app due to a delay in the software that positioned the delayed log out button in the same location as the button they had hit on the previous screen, such that the log out button appeared under their finger just as they attempted to hit the button again.

Some of the favorite features of the Ecobee Smart Si were the ability to show the indoor and outdoor temperature on the main screen, the smartphone app, the MENU button, and the BACK button, which returned the user to the previous screen.

REPORT CARD

Ease of Use	64%
Feel and Sound	73%
Appearance	79%
Task Efficiency	57%
Preference	71%
Overall Grade	A-

Feel and Sound

Most participants liked the feel and quiet yet audible sound of the buttons. A few thought the button sound should be a bit louder, while others thought it was too loud.

Appearance

Participants liked the smooth clean lines and fun modern look of the Ecobee. They appreciated the simple intuitive buttons. Several remarked on the crispness and readability of the text and the bright colors of the display, but most wished the screen were bigger.

9. Energate Foundation FZ100

Of all the thermostats tested, the Energate Foundation may have had the most mixed results. Some participants loved the look while others hated it, some liked the energy saving and cost features while others considered them useless and untrustworthy.

Ease of Use

Some participants found the Foundation "fairly" or "pretty" easy to navigate, while others said it was "unintuitive," "NOT easy to use at all," or that they couldn't "understand the meaning of most of what is on the screen." One mistook the spinning fan symbol for a software-loading symbol. Another was unhappy with the labeling of the "Home" key, which they said "should be a starting point for all the adjustments, instead it is some cost per hour." A few participants disliked that all choices had to be confirmed to take effect, complaining that there were too many steps to make any change. Participants universally found the app difficult to use.

Feel and Sound

Nearly all participants liked the large soft buttons, which they found easy to push even "if you have long fingernails." One or two did not like the soft feel, thinking they felt "loose" and cheap. As with most other silent thermostats, some participants wished the Foundation would make some noise when completing task, while others were relieved that it was quiet.

REPORT CARD

Ease of Use	49%
Feel and Sound	60%
Appearance	50%
Task Efficiency	43%
Preference	42%
Overall Grade	C

Appearance

Although many participants liked the layout and easily readable text, most participants found the overall look of the Foundation unappealing, citing the large unit size, small screen with too much information, drab gray color, and a lot of "wasted space." One thought the resolution of the font was not good, and was surprised that the manufacturer would use such a small, cheap and old-fashioned screen on a thermostat with so many modern features.

10. Energate Pioneer Z100

Participants liked the simple looks and overall feel of the Pioneer, but disliked the layout and functionality of the buttons, which they said made the menus hard to navigate.

Ease of Use

Most participants found the Pioneer easy to use, with an easy to read display and responsive navigation, but many found the menus confusing and disliked the layout and functionality of the buttons. Several participants expressed frustration over having two sets of buttons that functioned as up-down buttons, not knowing which set to use. One opined, "I don't understand why there is an up/down button for warmer and cooler but also up arrows above the random buttons under the screen." Another wrote, "I don't like that the menu button is between the warmer/cooler buttons and that it is the same shape & size."

The videos, reviewed to shed light on the navigation problems, showed that some participants missed the "Accept" button when setting the target temperature, so their input was not saved. Others got lost in the different scheduling options offered because the names were so similar: quick schedule, program, or schedule.

Feel and Sound

Many participants liked the soft easy-to-push buttons and quiet functionality of the Pioneer, while others complained that there was "no sound at all" and thought the buttons were too small and sticky. Some wished the display was a touchscreen, and several thought the unit looked and felt cheap – especially for what they considered should be a fairly high-end unit, based on the availability of the accompanying smartphone app.

REPORT CARD

Ease of Use	56%
Feel and Sound	62%
Appearance	63%
Task Efficiency	56%
Preference	53%
Overall Grade	B-

Appearance

Participants were split over the size and shape of the Pioneer, with some appreciating its unique shape and low profile and others having reservations about the unit being taller than it is wide. Most found the display relatively easy to read, but a few complained that the smallest text was difficult to read. In addition, the Pioneer was accused of having an "old-school pixilated display" – a comment echoed in the Energate Pioneer's sibling, the Energate Foundation. Several liked the backlight and its accompanying dimming feature.

11. Cooper-Honeywell Utility Pro

While participants liked the idea of having a touchscreen thermostat, they found the touchscreen on the Honeywell Utility Pro somewhat difficult to read and unresponsive to touch.

Ease of Use

Nearly all participants remarked on the difficulty they had setting the time, day of the week, date and schedules on the Utility Pro. One issue complicating these tasks was that the minute button had to be pushed once for each minute change. Most testers also thought the fonts and buttons were too small, making it hard for some to push the right buttons.

Many comments focused on the poor contrast and non-dynamic nature of the display – meaning all the text and symbols were there at all times but contrast increased as needed. This resulted in the ghosting of any text that was not currently in use, giving the impression of a crowded screen and leaving testers uncertain as to which information was in play at the time. As one participant put it, "It shows on screen other numbers behind it from previous screens."

Feel and Sound

Participants liked that the Utility Pro had a touchscreen, but were less than impressed with the quality of it. Many participants had trouble getting the touchscreen to respond to their touch, having to push too hard and sometimes having to push twice. "When you touch the screen it wasn't reacting to my touch. Seems very cheap."

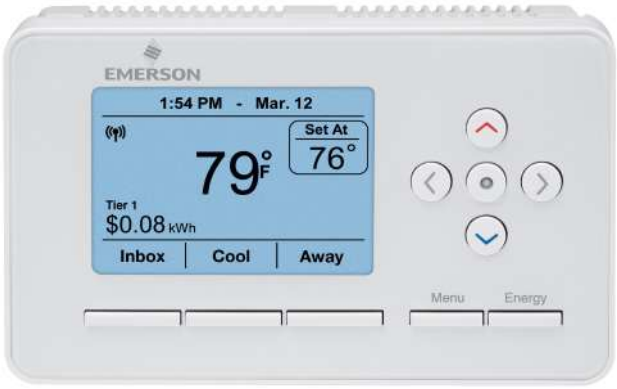
REPORT CARD

Ease of Use	45%
Feel and Sound	48%
Appearance	57%
Task Efficiency	55%
Preference	33%
Overall Grade	C

Appearance

Participants were about evenly split on the green mono screen, with comments ranging from "Looks fantastic!" to "Looks outdated, green screen with ugly black digits looks reminiscent of old computers from 80's," "the color is too green," and "This screen looks like obsolete technology." While the backlight was a benefit, some complained that it went off too quickly.

12. Emerson Smart Energy



Participants liked the clean modern look, crisp fonts, large screen, and intuitive navigation of the Smart Energy, but were unable to find a distinguishing "wow" factor.

Ease of Use

Nearly all of the participants who tested the Smart Energy found it easy to use, citing simple navigation and clearly defined buttons. In fact, of all the thermostats, the Smart Energy probably received the most compliments on the button layout. Participants particularly liked the availability and layout of the up-down-right-left arrows, along with the center button used to confirm settings. Also considered helpful were the Menu and Energy buttons, which were dedicated to those functions at all times. The remaining three buttons changed functionality as the menus were navigated, being placed directly below the dynamic labels on the screen, allowing expansion of features without cluttering the unit with too many input mechanisms.

A few testers expressed a wish for a touchscreen.

Feel and Sound

Many customers liked the quiet operation and feel of the Smart Energy buttons, but a few said they would like some confirmation noise and thought the buttons should be softer.

Appearance

Participants liked the size of the screen and the crispness of the text. Some praised the layout of the large current temperature in the middle of the screen and the smaller target “Set At” temperature in a box off to the side.

REPORT CARD

Ease of Use	68%
Feel and Sound	75%
Appearance	82%
Task Efficiency	59%
Preference	74%
Overall Grade	A

6 RECOMMENDATIONS

Based on the results of this study, the research team makes the following recommendations for future programs that involve thermostats.

1. **Thermostat procurement guidelines.** Based on the findings in this study, following are the recommended usability specifications for future thermostat procurement. Note that technical specifications must be developed in parallel.

   High priority:
   - Display should measure more than 4 square inches
   - Display should be crisp with good contrast
   - Display should have backlighting with settings for length of time on, or always on
   - Touchscreen, where present, should be at least 8 square inches
   - Touchscreen, where present, should be sensitive and responsive
   - Text and symbols should be large and easy to read
   - Meanings of all icons, symbols and labeling should be intuitive
   - Buttons and other input mechanisms should be of adequate size
   - Buttons should have a soft but solid feel – not too hard, not too mushy
   - Thermostat unit should be smaller than 40 square inches
   - Thermostat unit should look clean, simple, modern and attractive
   - Number of steps needed to reach any basic task screen should be minimal**

   Preferred:
   - Dynamic display with more than 2 colors
   - Basic instructions on or in the device
   - Volume for button noise, including off
   - Dimming for backlighting, including off
   - Confirmation of button press
   - Confirmation of task completed
   - Smart phone app or online portal, with consistency between interfaces
   - A “Home” button to take the user to the main screen
   - A “Back” button to take the user to the previous screen
   - A “Help” button with instructions for use

2. **Provide extra help for renters and the elderly.** If budget constraints disallow in-person, hands-on thermostat instructions for all customers, as much as possible, provide these services to renters and the elderly, who took significantly longer to complete the common tasks tested in this study.

3. ****Ease of Use testing.** Where possible, conduct a simplified version of this study to collect Ease of Use ratings for units under consideration. This effort would supplant “Number of steps needed to reach any basic task screen should be minimal.”

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APPENDIX A – ENERGY STAR THERMOSTAT SPECIFICATION

The following pages are reprinted from the U.S. Environmental Protection Agency's website, available online at:

http://www.energystar.gov/products/specs/node/161

"Residential Climate Controls Draft 3 Version 1 Specification"

ENERGY STAR® Program Requirements for Residential Climate Controls

Version 1.0 Eligibility Criteria Draft 3

Following is the **Draft 3** Version 1.0 product specification for ENERGY STAR qualified Residential Climate Controls. A product must meet all of the identified criteria if it is to earn the ENERGY STAR.

1) Definitions

A. Climate Control: A device that controls heating, ventilation, and air-conditioning (HVAC) equipment to regulate the temperature and humidity of the room or space in which it is installed. A Climate Control enables the customer to schedule comfort and energy-saving periods; for when the occupant is home, away or asleep, respectively. An energy-saving setpoint is automatically initiated during energy-saving periods and a comfort setpoint during occupied periods. Climate Controls may be capable of controlling one or more zones of a conditioned space. Climate Controls include the following:

1 Communicating Climate Control: A Climate Control with the ability to communicate with sources external to the HVAC system for purposes of energy management and remote control. External sources include but are not limited to: (1) customer signals from home computer or mobile device, (2) utility price signals and display messages, and, (3) home energy management device signals. Examples of capabilities provided by such systems include: Internet-enabled scheduling, remote Heating, Ventilating, and Air Conditioning (HVAC) control; messaging and energy rate alert display. The communication link may be wired or wireless.

2 Residential (Communicating) Climate Control: A Climate Control intended for installation in homes and dwellings. This device includes fan modes and a default program schedule suitable for typical residential usage.

3 Line Voltage (Communicating) Climate Control: A device that controls HVAC equipment to regulate the temperature of the room or space in which it is installed by controlling the line-voltage HVAC electrical load directly or indirectly through a line-voltage operating circuit.

4 Low Voltage (Communicating) Climate Control: A device that controls HVAC equipment to regulate the temperature of the room or space in which it is installed by controlling the applied energy in a National Electrical Code (NEC) Class 2 circuit.

B. Setpoint: The temperature setting in degrees Fahrenheit or degrees Celsius for any given time period.

C. Recovery, Adaptive: A Climate Control algorithm that initiates recovery in advance of the programmed time to result in the room temperature reaching the comfort setpoint at or near the programmed time.

D. Recovery, Heat Pump with Auxiliary Heat: A Climate Control algorithm that that minimizes the use of auxiliary heat to maximize energy savings.

E. Short Term Hold: This mode temporarily overrides the program setpoint. Short Term Hold shall be active only until the next scheduled program event.

F. Long Term Hold: This mode suspends the Climate Control program schedule until the long term hold mode is cancelled by the user.

G. Remote Interface (RI): A user interface for the Residential Climate Control that is independent from the traditional on-product user interface. Remote Interfaces, include, but are not limited to, mobile device and PC web interfaces and apps capable of remotely managing the Climate Control.

Note: As signaled in the Remote Interfaces discussion, EPA has included a definition for Remote Interface (RI). Definitions that are no longer needed have been removed for simplicity and clarity.

H. Heating Ventilation and Air Conditioning (HVAC) System Definitions

1 Heat Pump: A Heat Pump is a mechanical apparatus that normally consists of one or more factory-made assemblies that include an indoor conditioning coil(s), compressor(s) and a reversing mechanism to transfer heat to the premises from the outside air, ground or water in heating mode and from the premises to the outside air, ground or water in cooling mode.

2 Non-Heat Pump HVAC: For the purpose of this specification, non-heat pump HVAC encompasses all other HVAC equipment including, but not limited to fossil-fuel heat, central air conditioning, electric resistance heating and evaporative coolers.

3 Dual Fuel Heat Pump: For the purpose of this specification, a Dual Fuel Heat Pump integrates a heat pump with a fossil fuel furnace. To maximize efficiency of the system, the furnace is utilized for cold outdoor temperatures and the heat pump for milder temperatures. The Climate Control monitors outdoor temperature and selectively utilizes the two heat sources to optimize energy efficiency.

4 Auxiliary Heat: Electric resistance heat used to supplement the heat pump during periods of low temperature or rapid recovery.

2) Qualifying Products

ENERGY STAR qualified Residential Climate Controls must either be (1) a Communicating Climate Control, as defined in Section 1.A above, or be (2) field upgradeable to a Communicating Climate Control by installation of a communication module. Simultaneous availability of compatible communication modules is not required. Manufacturers are free to offer communications modules at a later date, for example when warranted by market conditions.

Note: Qualifying product criteria for scheduling that is duplicative of Technical Criteria has been removed. Similarly, packaging criteria to indicate HVAC compatibility has been moved to Other Criteria.

3) Energy Efficiency Criteria

Only those products referenced in Section 2, above, that meet the criteria below may qualify as ENERGY STAR.

A. Technical Criteria

1. Schedule periods - The product must enable 7-day program scheduling with a minimum of four possible schedule periods each day.

2. Default schedule - The product must provide a default, pre-programmed schedule with comfort periods and energy savings periods for when occupants are gone or asleep. This default schedule is intended to drive significant energy savings and shall be fully customizable in order to fit varying lifestyles and schedules. Detailed requirements for this schedule are provided in Tables 2 and 3, below.

Note The default pre-programmed schedule, specified in Section 3 does not include differing weekday and weekend settings. EPA has revised the above language for consistency with the Section 3 criteria.

In response to stakeholder feedback, EPA has removed a prescriptive reference to specific schedule period nomenclature. Stakeholders may elect to use event or activity based nomenclature or other identification/naming conventions that they deem appropriate.

In response to stakeholder feedback, EPA has removed the product packaging requirement to identify the product as for Residential use, only. Note that removal of this prescriptive requirement, while providing additional flexibility for manufacturers, does not alter the residential scope for this ENERGY STAR specification.

3. Temperature Stability – The product shall be capable of maintaining room temperature within ± 1°F of the setpoint temperature in accordance with NEMA DC 3-2008 section 4.5.2 Differential Tests. This may be a configurable setting.

4. Outdoor Temperature – Products that support dual fuel heat pump installations shall have access to and shall use outdoor temperature data to provide automatic cutover to/from the backup heat source based on installer configurable cutover temperatures.

Note: The requirement for outdoor temperature data has been relaxed such that it applies only to products that support dual fuel heat pump installations. There are various acceptable options for this data, including, for example, remote temperature sensor data and temperature data sourced from local weather forecasts.

The requirement to monitor and display humidity levels may pose a financial burden for climate control manufacturers and only facilitates seasonal energy savings in certain regions. Therefore, EPA will not require the climate control to display relative humidity. EPA notes that there is significant individual savings potential associated with Residential Climate Controls that includes the ability to control HVAC equipment based on temperature and humidity in certain use cases, e.g. unoccupied homes in hot humid regions. Thus, EPA proposes to encourage manufacturers to include this feature set in certain models, and will consider a humidity sensor field on the Qualified Product List.

5. Selectable Recovery Algorithms – The product shall be equipped with installer selectable recovery algorithms. When configured for non Heat Pump HVAC installations, the default recovery algorithm shall comply with the definition for Recovery, Adaptive (Section 1C). When configured for Heat Pump installations, that use electric resistance auxiliary heat, the default recovery algorithm shall comply with the definitions for Recovery, Adaptive **and** Recovery, Heat Pump with Auxiliary Heat (Section 1D).

   Exception – When a Communicating Climate Control is interconnected with a system capable of remotely managing recovery, it is permissible for recovery to be controlled by the remote system.

Note: Stakeholders have advised EPA that advanced energy management systems are capable of reducing energy consumption through remote management of the Residential Climate Control. These systems may dynamically vary recovery rates, recovery periods and setback setpoints to minimize energy usage for homes on an individual basis. Thus, EPA has included an exception that allows control systems to manage recovery in Connected Climate Controls.

6. Power Consumption

   a. Connected Climate Controls shall consume no more than 2.0 watts of average power, evaluated in accordance with Table 1.

   b. Climate Controls that do not include connected capability shall consume no more than

1.0 watt of average power, evaluated in accordance with Table 1.

c. Climate Controls that are powered solely by batteries are exempt from power consumption limits.

Table 1: Residential Climate Control – Power Consumption Measurement		
Product	**Average Power (W)**	**Measurement Parameters**
Climate Control	1.0	• 5-minute measurement period • Away mode cycled 1x
Connected Climate Control	2.0	• 5-minute measurement period • Away mode cycled 1x • Connection to device external to HVAC system, at least 1x

Note: It is EPA's intention to encourage certification of Climate Controls with modular communication options that allow users to install or upgrade communications at a later date. (See section 3.B.2) However, this presents a challenge in the context of the power consumption limit for communicating units. How can a unit demonstrate that it meets this power consumption requirement with a communications module that does not yet exist? EPA seeks stakeholder input on this point.

7. Default HVAC Schedule – Residential Climate Controls shall be shipped from the factory with an active, default program schedule, as defined in Tables 2 and 3, below. A minimum of four possible schedule periods is required. Default day and night (setback) periods must be at least 8 hours in duration.

Note: Stakeholders have requested that EPA allow manufacturers to determine how best to describe or name Climate Control schedule periods. In this draft, EPA has retained the default HVAC requirement, but has removed the prescriptive requirement to use specific schedule period nomenclature.

Table 2: Residential Climate Control Setpoints		
Setting	**Setpoint (Heat)**	**Setpoint (Cool)**
Morning	≤ 70°F	≥ 78°F
Day	Set-back at least 8°F	Set-up at least 7°F
Evening	≤ 70°F	≥ 78°F
Night	Set-back at least 8°F	≥ 78°F

Table 3: Residential Climate Control – Acceptable Schedule Periods and Setpoints			
Setting	**Time**	**Setpoint (Heat)**	**Setpoint (Cool)**
Morning	6 a.m.	70°F	78°F
Day	8 a.m.	62°F	85°F
Evening	6 p.m.	70°F	78°F
Night	10 p.m.	62°F	78°F

B. Communication Criteria

1. Open Access – Suitable documentation such as an application programming interface (API) or Interface Specification shall be available to 3rd party developers to enable access to the product's data reporting and remote management capabilities, as defined below in Sections 3.B.3 and 3.B.4.

2. Connectivity Standards – The following types of standards are recommended for connection outside of the HVAC system, using both built-in connectivity and/or modular connectivity:
   - Standards included in the Smart Grid Interoperability Panel (SGIP) Catalogue of Standards, and/or
   - Standards being considered for inclusion in the SGIP Catalogue of Standards, and/or
   - Standards adopted by the American National Standards Institute (ANSI) or a well established international standards organization, such as:
     - International Organization for Standardization (ISO)
     - International Electrotechnical Commission (IEC)
     - International Telecommunication Union (ITU)
     - Internet Engineering Task Force (IETF)

   More robust criteria may be considered in a future revision as relevant standardization efforts mature.

Note: Stakeholders have informed EPA that they are interested in protecting the user experience from poorly designed 3rd party apps or interfaces. EPA supports a market solution to this concern, and considers current examples of app qualification programs for smart phones such as the Android Market and iPhone App store to be acceptable models for manufacturer control of Residential Climate Control RIs. EPA has also clarified that the API or similar documentation may be limited to exposing only Data Reporting and Remote Management functionality as defined below.

In order to drive both open access and interoperability, EPA encourages the use of appropriate open communication standards, and strives to include consistent criteria across different ENERGY STAR product categories. As such, in this draft, EPA has added a recommendation for the use of standards included within or being considered for inclusion within the SGIP Catalogue of Standards and/or adopted by a well established Standards Developing Organization (SDO).

A previous proposal to phase in requirements to comply with NIST SGIP recommendations have been removed from this draft, based on the uncertainty of the development timeline for such standards, American National Standards, and those developed by a recognized international standards body such as IEC or ISO, which EPA encourages the use of. EPA will continue to monitor the NIST Smart Grid Interoperability Standards Project's work and may consider criteria associated will this body of work in future revisions, to encourage standardization, interoperability, communications security and open access.

3. Security – The product shall facilitate secure communications, including:

   a. **Basic authentication and authorization** so that only authorized devices or software applications can access the product, and

   b. **Security measures** to protect against unauthorized access.

4. Data Reporting – The product shall be capable of collecting and transmitting the following thermostat settings and data points on a periodic basis to connected devices external to the HVAC system. The product must be capable of recording data at least once every 60 seconds and transmitting data at least once every 5 minutes.

   - Unique Thermostat ID

- Room Temperature in °F or °C (0.1 °F resolution)
- Active Cool and Heat setpoints in °F or °C
- HVAC mode setting (off, Heat, Cool, auto)
- Active HVAC mode (off, Heat, Cool)
- Fan mode setting (off, on, auto)
- Active Fan mode (off, on)
- Current Hold mode type and state (e.g. Long Term – on)
- Current Away mode status (on, off)
- All Programmable settings, including program schedules & setpoints, hold modes, fan modes, HVAC modes and installer settings.
- Current Humidity reading and control mode

4. Remote Management – The product shall respond to the following remote control commands from authorized devices or software applications within 5 seconds. This criterion assumes receipt of the signal within 1 second of its transmission.

- Time synchronization
- Active Cool and Heat setpoints in °F or °C
- HVAC mode (off, Heat, Cool, auto)
- Current Humidity reading and control mode
- Fan mode (off, on, auto)
- Select hold mode type and status (e.g. Long Term – on)
- Select away mode status (on, off)
- All program schedule settings including times and setpoints for active and inactive schedules
- Select active program schedule

Note: To ensure the product is capable of responding to remote requests in near real-time, EPA has retained the 5 second response time criteria, but has revised the language to indicate that it is assumed that network latency is such that the requesting signal is received no later than 1 second after its transmission.

C. Ease of Installation Criteria

1. **Installation instructions** must utilize graphics and text, as appropriate, to guide the installer through both installation and configuration of the Residential Climate Control. These instructions shall include necessary installation steps and connection diagrams for all supported HVAC systems, both heat pump and non heat pump.

2. **Availability of Documentation** – Installer documentation must be posted on the manufacturer's Web site in electronic format and must be available for at least 10 years after cessation of product manufacture.

3. **HVAC Wiring Terminal Designations** shall be clearly labeled. It is recommended that Low Voltage Climate Controls use labels that comply with Table 5-1 in NEMA DC 3-2008. EPA notes that Low Voltage Climate Controls that use wired or wireless digital data interfaces between the Climate Control and the controlled HVAC equipment do not follow NEMA DC 3-2008. Line Voltage Climate Controls shall be marked to identify the Line, Load and Earth terminals.

Note: In response to stakeholder concerns that wiring terminal criteria were overly prescriptive and would drive up product cost, the HVAC wiring terminal criteria have been made less strenuous. Labels that comply with Table 5-1 in NEMA DC 3-2008 are recommended, but no longer mandatory.

4. **Batteries** – The product shall use commonly available batteries free of special handling and/or hazardous waste disposal requirements. This requirement is only applicable to products that use non-rechargeable batteries.

5. **Battery Life** – The product shall be designed for a typical battery life of a minimum of 12 months. This requirement is only applicable to products that use non-rechargeable batteries.

Note: In response to stakeholder concerns, battery requirements have been revised to clarify applicability only to products that use non-rechargeable batteries.

D. Residential Climate Control Ease of Use Criteria:

As illustrated in Figure 1, there are three approaches to demonstrate acceptable ease of use for Residential Climate Controls:

- Path 1 – Prescriptive Ease of Use – Compliance with both core prescriptive ease of use criteria **and** additional prescriptive ease of use criteria.
- Path 2 – Performance -Based Ease of Use – Compliance with both core prescriptive ease of use criteria **and** performance-based ease of use criteria.
- Path 3 – Performance -Based Ease of Use with Remote Interface:
    - Compliance with both core prescriptive ease of use criteria and a limited set of performance-based ease of use criteria without the use of the RI, and
    - Compliance with the entire performance-based ease of use criteria, with users interacting with the product only with an associated RI.

Note EPA is proposing modified criteria that allow for streamlined qualification testing of *Connected* Residential Climate Controls associated with at least one RI. EPA believes that these changes will enable qualification of lower cost Climate Controls and increase consumer choice by encouraging more complex and interactive tasks to be performed from RIs on devices such as PCs, smartphones & tablets that are likely to foster a favorable user experience.

Connected Residential Climate Controls that may be managed by *Remote Interfaces* (RIs) have come to market in greater number over the last few years. EPA believes this emerging shift to remote energy management presents significant opportunities for energy savings. Recognizing this market shift, EPA is proposing allowing Residential Climate Controls with remote interfaces to earn the ENERGY STAR.

APPENDIX B – CALIFORNIA THERMOSTAT STANDARDS

The following pages are reprinted from the California Energy Commission's Title 24 Building Standards Joint Appendices, available online at:

http://energy.ca.gov/title24/2013standards/rulemaking/documents/final_rulemaking_documents/44_Final_Express_Terms/2013_JA_FINAL.pdf

Joint Appendix JA5

Appendix JA5 - Technical Specifications For Occupant Controlled Smart Thermostats

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JA5.1 Introduction

The Occupant Controlled Smart Thermostat (OCST)[2] shall be self-certified by the manufacturer to the Energy Commission to meet the requirements described in this section. This document provides a high level technical specification for an OCST. All OCSTs shall comply with the specifications set forth in this document or a specification approved by the Executive Director. This specification focuses on three interfaces that the Energy Commission has determined shall be supported by all OCSTs:

(a) Communications Interface
(b) User Display and Interface
(c) HVAC System Interface

Sections within this document address each interface in terms of its hardware and software characteristics. This specification is intended to compatible with NEMA Standards Publication DC 3-2008 – "Residential Controls – Electrical Wall-Mounted Thermostats"[3] unless otherwise specified.

The Communications Interface is defined as a set of logical services that may be performed over a physical network interface connected to either an expansion port or an internal communications device. The communications interface is designed to permit a variety of intended uses for OCSTs including remote energy management services, to the extent that occupants voluntarily enable such services. To the extent possible, this document strives to be compatible with related efforts underway (e.g. National Institute of Standards and Technology (NIST) Smart Grid Interoperability Panel (SGIP), Open Smart Grid, etc.).

The following elements are addressed in this document:

(a) Support for the basic HVAC terminal interface specification
(b) Support for an internal communications device or for an expansion port that will allow for the installation of a removable module to enable communications with the thermostat.

The following sections describe these and other elements of the specification in more detail.

JA5.2 Required Functional Resources

JA5.2.1 Setback Capabilities

All OCSTs shall meet the requirements of Section 110.2(c). Thermostats for heat pumps shall also meet the requirements of Section 110.2(b).

JA5.2.2 Communication Capabilities

OCSTs shall include communication capabilities enabled through either

(a) At least one expansion port which will allow for the installation of a removable module containing a radio or physical connection port to enable communication; or
(b) Onboard communication device(s)

2 A networked system of devices which is capable of receiving and responding to Demand Response Signals and provides equivalent functionality as required by Reference Joint Appendix JA5~~,~~ shall be considered equivalent to an OCST.

3 NEMA DC 3-2008 - http://www.nema.org/Standards/Pages/Residential-Controls-Electrical-Wall-Mounted-Room-Thermostats.aspx

JA5.2.3 OCST Messages and Attributes

The OCST communications capabilities shall enable Demand Responsive Control through receipt of Demand Response Signals or price signals. After OCST communication is enabled and the occupant has enrolled in a Demand Response program or subscribed to receive demand response or pricing related messages or information updates, the OCST shall be capable of both receiving and responding to Demand Response Signals. The OCST with communications enabled recognizes two basic system event modes: price response and Demand Response Periods. Both basic system event modes can be overridden by the occupant.

JA5.2.3.1 Price Signals

Price signals allow the utility or another entity selected by the occupant to send a signal or message to the occupant's OCST to provide pricing information to the occupant and initiate Demand Responsive Control for the Demand Response Period utilizing a Demand Response Signal.

Price signal attributes and requirements shall be specified within the messaging protocol utilized by the utility or other entity selected by the occupant.

JA5.2.3.2 Demand Response Periods

This event class allows the utility or another entity selected by the occupant to initiate Demand Responsive Control for the Demand Response Period utilizing a Demand Response Signal.

Demand Response Signal attributes and requirements shall be specified within the messaging protocol utilized by the utility or other entity selected by the occupant.

If a price signal or Demand Response Signal is received and validated, but conflicts with a prior message, the newer message shall supersede the previous message and any continuing action for the prior message is automatically terminated by the OCST (unless the subsequent message attempts to initiate an action that has been disapproved by the occupant).

JA5.2.4 Event Response

Event response, unless overridden by the occupant or modified by an energy management control system or service, may be triggered by price signals or Demand Response Signals. The OCST shall provide one set of event responses for price signals and one set of event responses for Demand Response Signals. The responses may be common for both types of events.

OCSTs, with communications enabled, shall be capable of receiving and automatically responding to the Demand Response Signals as follows:

(a) A Demand Response Signal shall trigger the OCST to adjust the thermostat setpoint by either the default number of degrees or the number of degrees established by the occupant.
(b) When a price signal indicates a price in excess of a price threshold established by the occupant, the OCST shall adjust the thermostat setpoint by either the default number of degrees or the number of degrees established by the occupant.
(c) In response to price signals or Demand Response signals, the OCST shall default to an event response that initiates setpoint offsets of +4°F for cooling and -4°F for heating relative to the current setpoint.
(d) The OCST shall have the capability to allow occupants or their representative to modify the default event response with occupant defined event responses for cooling and heating relative to the current setpoint in response to price signals or Demand Response Signals.
(e) Override Function: Occupants shall be able to change the event responses and thermostat settings or setpoints at any time, including during price events or Demand Response Periods.
(f) The Demand Response Signal shall start the Demand Response Period either immediately or at a specific start time as specified in the event signal and continue for the Demand Response Period specified in the Demand Response Signal or until the occupant overrides the event setpoint.

(g) The thermostat's price response shall start either immediately or at a specific start time as specified in the pricing signal and continue for the duration specified in the pricing signal or until the occupant overrides the event setpoint.
(h) The OCST shall have the capability to allow occupants to define setpoints for cooling and heating in response to price signals or Demand Response signals as an alternative to the default event response.
(i) At the end of a price event or Demand Response Period, the thermostat setpoint shall be set to the setpoint that is programmed for the point in time that the event ends or to the manually established setpoint that existed just prior to the Demand Response Period.

JA5.2.5 Other Required Capabilities

Unless the messaging protocol contains randomization or restoration delay logic, OCSTs shall provide a mechanism, such as a randomized delay, to prevent all of the OCSTs within a demand-response area from ending the demand-response event at the same time. This mechanism can be implemented within the control logic of the OCST, within the control logic of the demand-response signaling system, or within the control logic of the communication network between the OCST and the demand-response signaling system. The display of the thermostat shall accurately indicate the end of the event, accounting for any delays or advances provided by this mechanism. The specific maximum restoration delay for restoration after a Demand Response Period shall be 30 minutes or alternatively can be defined within the Demand Response Signal for that event.

JA5.3 Functional Descriptions

JA5.3.1 Communications Interface

The communications interface has two aspects – the physical interface and the logical interface.

The physical communications interface includes a one- or two-way communications interface as selected and specified by the occupant's utility, information update service or Demand Response service provider and enabled by either onboard communications devices or a communications module in the case of an expansion/communication port. There is no mandated specification for the physical communications protocol. However, the communications capabilities shall enable Demand Responsive Control through receipt of Demand Response Signals based on communications standards (including but not limited to ZigBee (IEEE 802.15.4) or WiFi (IEEE 802.11)).

The logical interface consists of the information model used to represent messages sent to the OCST. There is no mandated specification for the logical interface , but direction is provided as "standards based messaging protocols (including but not limited to Smart Energy Profile (SEP), OpenADR or others defined in the Smart Grid Interoperability Panel (SGIP) Catalog of Standards (CoS)[4])" or as defined by the occupant's information update service or Demand Response service provider.

JA5.3.2 Expansion/Communication Port

This port is available to be used by a module supporting one-way or two-way communications supporting standards based communication protocols as described in Section 5.3.1. The module shall also enable standards based messaging protocols (including but not limited to Smart Energy Profile (SEP), OpenADR or others defined in the Smart Grid Interoperability Panel (SGIP) Catalog of Standards (CoS)) or as defined by the occupant's information update service or Demand Response service provider.

When the Expansion/Communication port is unpopulated, the thermostat shall function as a programmable setback thermostat and shall meet the requirements of Sections 110.2(b) and (c).

The removable module may also provide a means of memory storage, logging, and firmware upgrade. The requirements associated with the expansion interface are:

(a) The expansion/communication port shall be readily accessible to the occupant for installing and removing the communication module.

4 http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/SGIPCoSStandardsInformationLibrary

(b) Installation of the module shall upgrade the programmable setback thermostat to an OCST.

(c) After communications are enabled[5] and the occupant has enrolled in a Demand Response program or subscribed to receive demand response related messages or information updates, the OCST shall be capable of both receiving and responding to Demand Response Signals.

The OCST's expansion port interface has no mandated configuration or design specification.

JA5.3.3 Onboard Communications Devices

When onboard communication devices are present, the thermostat or HVAC control system shall be equipped with the capability to enable or disable the onboard communication device(s). The switch or interface to enable or disable onboard communications shall be readily accessible to the occupant.

When onboard communications are disabled, the thermostat shall function as a programmable setback thermostat and shall meet the requirements of Section 110.2(c). Thermostats for heat pumps shall also meet the requirements of Section 110.2(b).

JA5.3.4 User Display and Interface

The OCST shall have the capability to display information to the user. The following information shall be readily available whenever the OCST display is active:

(a) communications system connection status,

(b) an indication that a Demand Response Period or pricing event is in progress,

(c) other maintenance-related information,

(d) the currently sensed temperature,

(e) the current setpoint.

JA5.3.5 Required Functional Behavior

(a) Clock Operation. The clock mechanism enables the OCST to execute temperature setpoints scheduled by the occupant. It also supports other timing functions such as start-time, end-time and duration for coordination of Demand Response Periods and price signal response.

The OCST shall provide a pair of programmable thermostat setpoint time and temperature parameters for at least four operating periods that collectively govern thermostat operation during the 24-hour day.

Accuracy to a precision of one minute is acceptable for this operating environment and the applications being considered.

The clock in an OCST may be set by the occupant, using the OCST's human-machine interface. Alternatively, an OCST with communications enabled may be set or synchronized by the occupant's selected service provider.

(b) Normal Operation. Normal operation of an OCST is defined to be the OCST's prevailing mode of operation as determined by the occupant's prior settings and use of features[6] provided by the OCST manufacturer's design. Aspects of normal operation of an OCST may be modified or interrupted in response to occupant subscribed price signals or when Demand Response Periods are in progress, but only to the extent specified by occupants or their representatives.

5 The removable module, or gateway for a networked system of devices, for enabling communications can be selected and installed at the time of enrollment in a Demand Response program or subscription to receive demand response related messages or information updates.

6 The specific design of such features (e.g. HOLD, OVERRIDE) is defined by individual manufacturers and not by this document.

Unless an occupant has elected to connect the OCST to an energy management control system or service that provides for alternate strategies, the OCST shall provide a mode of operation whereby it controls temperature by following the scheduled temperature setpoints.

Occupants shall always have the ability to change OCST settings or use other features of an OCST during an event. Those changes may alter what is considered to be the prevailing mode of operation when a Demand Response Period is terminated and the OCST returns to normal operation.

(c) Demand Responsive Control. Upon receiving a price signal or a Demand Response Signal, OCSTs shall be capable of automatic event response by adjusting the currently applicable temperature setpoint by the number of degrees indicated in the temperature offset (heating or cooling, as appropriate).

Override: OCSTs shall allow an occupant or their representative to alter or eliminate the default response to price signals or Demand Response Signals, and to override any individual price response or Demand Responsive Control and allow the occupant to choose any temperature setpoint at any time including during a price event or a Demand Response Period.

When the price signal changes to a non-response level or the Demand Response Period is concluded, OCSTs shall return to normal operation. The thermostat setpoint shall be set to the setpoint that is programmed for the point in time that the event ends or to the manually established setpoint that existed just prior to the Demand Response Period.

The OCST shall also be equipped with the capability to allow occupants to define setpoints for cooling and heating in response to price signals or Demand Response Signals as an alternative to the default event response. The default setpoint definitions unless redefined by the occupant shall be as follows:

1. The default price response or Demand Response Period setpoint in the cooling mode for OCSTs shall be 82°F. The OCST shall allow the occupant to change the default event setpoint to any other value.
2. The default price response or Demand Response Period setpoint in the heating mode for OCSTs shall be 60°F. The OCST shall allow the occupant to change the default event setpoint to any other value.
3. The OCST shall ignore price response or Demand Response Period setpoints that are lower (in cooling mode) or higher (in heating mode) than the programmed or occupant selected prevailing setpoint temperature upon initiation of the price event or Demand Response Period.
4. By default, thermostats shall not be remotely set above 90°F or below 50°F. Occupants shall have the ability to redefine these limits. This measure protects occupant premises from extreme temperatures that might otherwise be imposed by event responses, should the occupant already have a very high or low temperature setpoint in effect.

The occupant may still override or change the setpoint during all price events and Demand Response Periods. Price signal response and Demand Responsive Control only modify the operating range of the thermostat. They do not otherwise affect the operation and use of features provided by the manufacturer's design.

JA5.3.6 Restoring Factory Installed Default Settings

The OCST shall include the capability to allow the occupant to restore the factory installed default settings.

JA5.3.7 Security

Demand Response Signal security attributes and requirements shall be specified within both the communications standard and the messaging protocol utilized by the utility or other entity selected by the occupant. The OCST communications system shall consider relevant security issues and potential cyber-attacks[7].

JA5.4 The HVAC System Interface

HVAC wiring terminal designations shall be clearly labeled. OCSTs shall use labels that comply with Table 5-1 in NEMA DC 3-2008. It is noted that OCSTs using wired or wireless digital data interfaces do not directly follow NEMA DC 3-2008.

JA5.5 Terminology

Current Setpoint	The setpoint that existed just prior to the price event or Demand Response Period.
Demand Response	See Joint Appendix JA1- Glossary.
Demand Response Period	See Joint Appendix JA1 – Glossary.
Demand Response Signal	See Joint Appendix JA1 – Glossary.
Demand Responsive Control	See Joint Appendix JA1 – Glossary.
Energy Management Control System	See Joint Appendix JA1 – Glossary.
Override	Refers to an occupant adjusting thermostat settings to either not respond to a Demand Response Signal or adjusting the setpoint compared to the OCST's programmed response to a price signal or Demand Response Signal.
Price Signal	is a signal sent by the local utility, Independent System Operator (ISO), or designated curtailment service provider, information update service or aggregator, to an enrolled or subscribed customer, indicating a price or other economic indicator that can trigger OCST Demand Responsive Control.
Price Event	Refers to a change in pricing sent to the OCST from the utility or the occupant's selected demand response provider.

7 A thorough discussion of security issues may be found at: http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/CyberSecurityCTG.

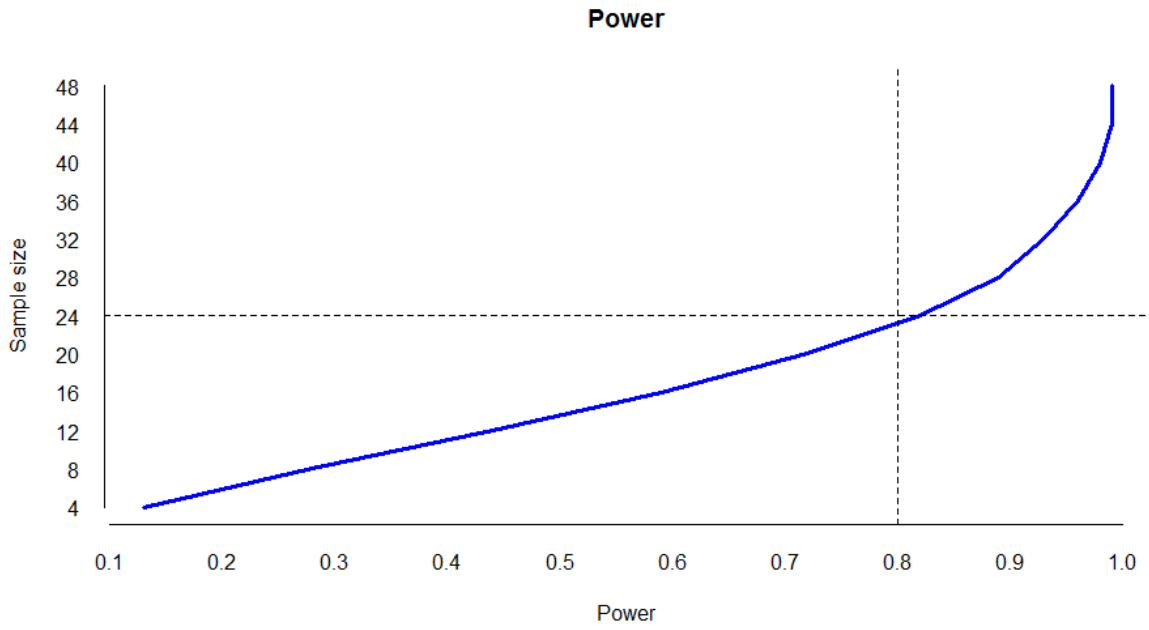
APPENDIX C – SAMPLE SIZE POWER ANALYSIS

Figure 20 plots the sample size requirements as a function of desired statistical power using the following parameters:

- Number of groups = 12 (one group per thermostat)
- Effect size = 0.25 (medium)[2]
- Significance level = 0.05 (95% confidence)

Figure 20 shows that a standard power of 0.8 requires that at least 24 participants test each thermostat. A sample size of 30 would provide a power greater than 0.9, which is generally considered excessive.

FIGURE 20. SAMPLE SIZE AND POWER FOR 12 GROUPS WITH 0.25 EFFECT SIZE, 95% CONFIDENCE LEVEL



[2] Effect sizes of 0.10, 0.25, 0.40 are standard for ANOVA power calculation.

APPENDIX D – RECRUITMENT SCRIPT

Hello, May I speak to **(NAME ON LIST)**?

1) Gender **(RECORD BY OBSERVATION)**
   a) Male
   b) Female

2) Hello, my name is _____ and I'm from [COMPANY] and we are calling on behalf of SMUD to see if you would be interested in evaluating some new residential technologies. The testing will take about 90 minutes. For your participation, you would be compensated $____. Does this sound like something you might be interested in?
   a) Yes----------→ CONTINUE
   b) No----------→ **TERMINATE**

3) During the session, you will be given the opportunity to try out two items. After each one, there will be a short group discussion about your experience. The discussions will be held entirely in English. Do you feel comfortable speaking in a situation where English is the only language?
   a) Yes----------→ CONTINUE
   b) No----------→ **TERMINATE**

4) On a scale from 1 to 5 with 5 being extremely comfortable, how comfortable do you feel using the following appliances and technologies?

a) Washer and dryer	1	2	3	4	5
b) Thermostat	1	2	3	4	5
c) Computer	1	2	3	4	5
d) Digital timer (e.g for pool pump or lawn sprinkler)	1	2	3	4	5
e) Remote control for TV equipment	1	2	3	4	5
f) Smart phone	1	2	3	4	5

5) In what year were you born?
   a) Year _____
   b) Refused → **TERMINATE**

6) How would you describe your highest level of education: less than high school, a high school graduate, some college, college graduate, or advanced degree?
   a) Less than high school
   b) High school grad
   c) Some college
   d) College grad
   e) Advanced degree
   f) (Refused/Don't know) **TERMINATE**

7) Have you or has anyone in your household ever worked for any of the following?
   a) Market research company ----------> **If YES, TERMINATE**
   b) News media----------> **If YES, TERMINATE**
   c) Public or private utility company ----------> **If YES, TERMINATE**
   d) The energy industry ----------> **If YES, TERMINATE**
   e) Marketing or advertising company----------> **If YES, TERMINATE**

8) Do you currently own or rent your home or apartment?
   a) Own
   b) Rent
   c) (Refused/Don't Know)

9) Which of the following categories includes your total annual household income before taxes: less than 50,000; 50,000 to 99,999; 100,000 to 150,000; more than 150,000?
   a) Less than $50,000
   b) $50K-$99,999K
   c) $100K-$150K
   d) More than $150K
   e) (Refused/Don't know)

10) There are several sessions available on April 19, 20 and 22nd. Will you be able participate on one of these days?
   a) Yes----------→ CONTINUE
   b) No----------→ **TERMINATE**

SCHEDULE DAY AND TIME

As a courtesy reminder, we'll call you on the day before the session. Is **[PHONE NUMBER]** still the best number to reach you?

We look forward to seeing you on **[DAY & DATE & TIME**].

THANK YOU!

APPENDIX E – PARTICIPANT NON-DISCLOSURE AGREEMENT

PARTICIPANT AGREEMENT / RELEASE FORM

I understand that I am a participant in a research project. At no point will anyone try to solicit any materials to me. This project is strictly for research purposes. As part of my participation, I understand that I may be video and audio taped, and that these tapes will be used in analysis of this research and possibly for future internal training purposes.

I also understand that the subject matter of this group is confidential. I agree not to discuss any of the information talked about during this meeting outside of this discussion group. I understand that I will not disclose anything that is discussed in today's discussion with any third party, including co-workers, relatives, neighbors, friends, or any other individuals.

I _____ , hereby agree to maintain the confidentiality of information disclosed during focus group or interview sessions as follows:

1. "Confidential Information" means information or material obtained or observed while attending this focus group session. By example and without limitation, Confidential Information includes any and all information concerning techniques, ideas, processes, trade secrets, innovations, discoveries, improvements, research or developments and test results, data, strategies, products, branding and forecasts.

2. All notes, reference materials, memoranda, documentation and records in any way incorporating or reflecting any of the Confidential Information shall belong to Elliott Benson's client and I agree to turn over all copies of such materials in my possession to Elliott Benson upon request.

3. I shall at all times hold in trust, keep confidential and not disclose to any third party or make any use of the Confidential Information.

4. Further, I hereby authorize Elliott Benson's client to use the contents or results of any record of my participation in this group discussion without limitation. By signing this agreement, I am relinquishing any interest in all opinions, ideas, or other information that is collected in the course of this research project. I also understand that the focus group may be recorded by audio and/or video.

_____
Print Name

_____
Signature

_____
Date

APPENDIX F – FACILITATOR'S GUIDE

Thermostat Usability Testing - #13-651

Facilitator's Guide

April 19, 20, 22

A. WELCOME and INTRODUCTIONS – 15 minutes

1) Introduce self and explain research purpose
   a. Thank participants for coming and participating in the research.
   b. I'm [Facilitator], an independent researcher who helps organizations tests products and look for ways to improve them.
   c. Purpose of today's study is to have consumers review thermostats both for ease of use and likeability. We are looking to understand what features are most important to consumers.
   d. Imagine you are shopping for a thermostat and have the opportunity to try out two models.

2) Describe room set-up and process
   a. Booths with twelve different thermostats; each of you have been assigned to two.
   b. For each one, we'd like you to complete a set of common tasks – for example, increasing the temperature, or setting it for vacation – and also complete a survey about its features. (Show consumers the task booklet)
   c. You will have 20 minutes to complete the tasks and the survey for each thermostat.
   d. Before opening the task booklet, you will be given a minute to play with your thermostat.
   e. The tasks are provided at each station in the Task Booklet. There is one task per page.
   f. As you complete each task, write in the answer or simply mark the box labeled "Done" to indicate that you completed it. (show the checklist) For example, if you are asked to identify a scheduled temperature, write the degrees here in the box. If you are asked to change a setting, simply check the box to indicate when you are done.
   g. If you spend more than 2 or 3 minutes on a single task and don't feel you will be able to complete it, mark the box "Not Done." After marking either the "Done" or "Not Done" box, turn to the next page and begin the next task.
   h. We will be timing each task in order to see which thermostats are easiest to use so if you need to do something other than the task, please do it after all the tasks are

completed so it doesn't impact the timing. The timer will start for each task when you turn the page and will end when you check either the "Done" or "Not Done" box.

i. When you reach the end of the booklet, please turn to the survey sheet and fill out the questions on the survey about the thermostat you just used. The first section asks about the ease of use (etc.). The second section wants you to rate how the thermostat FEELS, meaning does it feel like it's good quality, does it have the right pressure for the buttons, and things like that. The third section asks about how the thermostat LOOKS – again, think about the quality, and maybe how it would look hanging on your wall at home.

j. Please stay at your station until I indicate that the twenty minutes is up. Then, we'll come back to the table and have a brief group discussion before you try the second thermostat you've been assigned.

k. To help us analyze the thermostat tests, we will be videotaping the process. You also may have noticed the one-way mirror behind me. Some of the people I'm working with may come to observe some of the testing, but they stay in the back room so it's less crowded and not distracting to the test or our discussion as they come and go.

3) Four key points to emphasize:

a. We value candid opinions. If you do not like the way your thermostat looks, feels, or works, it's important to let us know on your surveys and in the discussions. We didn't design these thermostats ourselves so you won't offend anybody by being completely honest.

b. There are no right or wrong answers, only your opinions. I'm not expecting consensus. Each person has their own preferences so differences of opinion are okay and expected.

c. We are testing the thermostat, not the user! Do not worry about making mistakes or not being able to complete the task. If you are struggling and not able to complete a task easily, it is the fault of the thermostat design, not you. It's important for us to learn which thermostats are difficult or easy to use and why.

d. It's very very important that each of you do your best to complete the tasks and survey on your own – without any help from your neighbors. So please no talking at all. If you have questions about the process, please ask me.

4) A few other logistics

a. Also in the room is our technical support staff. She will be monitoring the video equipment and handling any technical problems that come up.

b. [Tech Assistant] and I can only answer questions about the test process or if you think there is a technical malfunction. Since we are testing how easy or difficult it is to use the thermostats, we cannot answer questions about how your thermostat works or help you complete your tasks.

c. Does anyone have any questions before we get started?

B. TEST #1 – 20 minutes

1) Please proceed to your assigned thermostat booth.
2) Reminders:
   a. You have 1 minute to play with your thermostat before opening the task booklet. When I say "begin," please open your booklet and start the first task. When you complete the task, write in the answer if applicable or mark the box, "Done," turn the page and start on the next task. Continue until you've finished all the tasks.
   b. Remember, that if you spend more than 2 or 3 minutes on a single task and don't feel you will be able to complete it, it's okay to mark the box "Not Done" and skip to the next task.
   c. If you finish early, please stay quietly at your station. Use any extra time to make notes on your survey. Feel free to draw arrows and note what things you particularly like or don't like about this thermostat on the pictures provided.
3) Are there any questions?
4) (Check that technical staff is ready to begin video recording)
5) Is everyone ready? You may now begin. START TIMER

C. DISCUSSION #1 – 15 minutes

1) Time is up … please remove your checklist from the station, attach it to the back of your survey, and bring your survey back to the table with you.
2) Before we start the discussion and move on to the second thermostat test does anyone have any questions about the process?

As group discusses feedback, create chart of key strengths and weaknesses of thermostats.

3) Did anyone test a thermostat they thought …
   a. Was especially easy to use? Describe what made it easy.
   b. Was especially difficult or frustrating to use? Describe what was difficult.
   c. Had a feature you especially liked? Describe.
   d. Had a feature you especially disliked? … Describe.

(Note: in the first discussion, do NOT probe as to which thermostat they used to minimize any potential bias)

D. TEST #2 – 20 Minutes

1) Please proceed to your second assigned thermostat booth.
2) Don't forget – no talking.
3) (Check that technical staff is ready to begin video recording.)
4) Is everyone ready? You may now begin. START TIMER

E. DISCUSSION #2 – 15 Minutes

1) Time is up. Please remove your checklist from the wall, attach it to the back of your survey, and bring your survey with you to the table.
    e. Let's go around the table and hear from each person which of the two thermostats you tried you liked best and what features made you prefer that one over the other one.
2) Look at the list of possible advanced features on your survey:
    a. Which ones are important enough to you to make you want to seek out a thermostat with that feature? What makes that important to you?
    b. Which features would you not want to have on your thermostat? What makes you feel that way?
3) Are there any other aspects of the thermostat design that we haven't talked about yet that are important to you when choosing a thermostat for your home? Or specific improvements you'd like to see?

F. WRAP-UP – 5 minutes

1) Any final advice you would give to thermostat designers to develop a thermostat that is ideal for you?
2) Thank respondents and instruct them to see hostess for their incentive.

APPENDIX G – SURVEY EXAMPLE

THERMOSTAT #1

Do you have this thermostat at home?

Yes No

1	Rate EASE OF USE and UNDERSTANDING	Lousy ---------- Fine---------- Amazing!										*Doesn't apply*
a	Information on the screen	1	2	3	4	5	6	7	8	9	10	*NA*
b	Buttons, dials and switches	1	2	3	4	5	6	7	8	9	10	*NA*
c	Meanings of words and symbols	1	2	3	4	5	6	7	8	9	10	*NA*
d	Menu navigation	1	2	3	4	5	6	7	8	9	10	*NA*
e	Overall ease of use	1	2	3	4	5	6	7	8	9	10	*NA*

Specific likes:

Specific dislikes:

2	Rate how the thermostat FEELS and SOUNDS	Lousy ---------- Fine---------- Amazing!										*Doesn't apply*
a	Buttons	1	2	3	4	5	6	7	8	9	10	*NA*
b	Touchscreen	1	2	3	4	5	6	7	8	9	10	*NA*
c	Dials	1	2	3	4	5	6	7	8	9	10	*NA*
d	Switches	1	2	3	4	5	6	7	8	9	10	*NA*
e	Overall feel and sound	1	2	3	4	5	6	7	8	9	10	*NA*

Specific likes:

Specific dislikes:

3	Rate how the thermostat LOOKS	Lousy ---------- Fine---------- Amazing!										*Doesn't apply*
a	Layout of the screen and buttons	1	2	3	4	5	6	7	8	9	10	*NA*
b	Size of the screen	1	2	3	4	5	6	7	8	9	10	*NA*
c	Color(s)	1	2	3	4	5	6	7	8	9	10	*NA*
d	Readability of the smallest text	1	2	3	4	5	6	7	8	9	10	*NA*
e	Overall appearance of the thermostat	1	2	3	4	5	6	7	8	9	10	*NA*

Specific likes:

Specific dislikes:

4	Imagine a friend or neighbor needs a new thermostat. Would you recommend they consider buying this one?	No way ---------- Maybe ---------- Definitely!										*Doesn't apply*
		1	2	3	4	5	6	7	8	9	10	*NA*

Why?

5 Based on your experience using this thermostat, what do you think is a reasonable price to charge for it? $ _____

6	**Imagine that the thermostat in your home suddenly dies and your mechanic offers a choice between the thermostats you just reviewed - at the same price. Please circle the thermostat you would choose to have installed.**	1	2

What's the main reason for your choice?

7	**Do you think you would find the following features useful on a thermostat in your home?**	No way ------ Maybe ------ Definitely!										*Not sure*
a	**Auto-Schedule**: The thermostat programs your temperature preferences for you, based on your adjustments in the first week or two.	1	2	3	4	5	6	7	8	9	10	*?*
b	**Auto-Away**: The thermostat automatically adjusts the temperature when it senses your home is unoccupied.	1	2	3	4	5	6	7	8	9	10	*?*
c	**HVAC Energy Display**: The thermostat displays the amount of electricity used by your central heating and cooling system.	1	2	3	4	5	6	7	8	9	10	*?*
d	**Home Energy Display**: The thermostat displays the amount of energy used by your home.	1	2	3	4	5	6	7	8	9	10	*?*
e	**Efficiency Indicator**: The thermostat indicates when you adjust it to an energy efficient temperature setting.	1	2	3	4	5	6	7	8	9	10	*?*
f	**Time to Temperature**: The thermostat displays how long it will take to reach the target temperature.	1	2	3	4	5	6	7	8	9	10	*?*
g	**Online Account**: You can use a computer to adjust your thermostat settings remotely	1	2	3	4	5	6	7	8	9	10	*?*
h	**Smart phone app**: You can use a smart phone to adjust your thermostat settings remotely	1	2	3	4	5	6	7	8	9	10	*?*
i	**Color display**: The main display has more than 2 colors.	1	2	3	4	5	6	7	8	9	10	*?*
j	**Touchscreen**: The main screen is also an input device.	1	2	3	4	5	6	7	8	9	10	*?*
k	**Outdoor temperature**: The thermostat can display the outdoor temperature	1	2	3	4	5	6	7	8	9	10	*?*
l	**Price response**: The thermostat automatically adjusts settings based on your input and the price of electricity	1	2	3	4	5	6	7	8	9	10	*?*
m	**Precool**: The thermostat automatically cools your home before a high-priced peak period	1	2	3	4	5	6	7	8	9	10	*?*
n	**Proximity**: Your thermostat knows your location and automatically switches between home and away settings	1	2	3	4	5	6	7	8	9	10	*?*
o	**Parental Controls**: The thermostat allows changes to settings only after a password is provided	1	2	3	4	5	6	7	8	9	10	*?*

Comments (Feel free to write on the back if you need more room)

APPENDIX H – REGRESSION MODELS

DATA DICTIONARY

TABLE 13. DATA DICTIONARY FOR VARIABLES INCLUDED IN THE REGRESSION MODELS

Variable	Description	Data type
Participant_<$50k	Participant household income is less than $50,000	Boolean
Participant_$50-100k	Participant household income is $50,000-$100,000	Boolean
Participant_Age	Participant age	Continuous
Participant_College	Participant has at least a 4-year degree	Boolean
Participant_Male	Participant is male	Boolean
Participant_Renter	Participant rents their home	Boolean
Participant_SmartphoneIQ	Participant self-rated confidence using a smartphone	Continuous
Participant_ThermostatIQ	Participant self-rated confidence using a thermostat	Continuous
Tstat_Access_Smartphone	Remote control with SmartPhone App	Boolean
Tstat_Rated_Appearance	Overall appearance of the thermostat (Q3e)	Continuous
Tstat_Rated_Ease.of.Use	Overall ease of use of the thermostat (Q1e)	Continuous
Tstat_Rated_Feel.and.Sound	Overall feel and sound of the thermostat (Q2e)	Continuous
Tstat_Screen_Color.Display	Color display screen (more than 2 colors)	Boolean
Tstat_Screen_Size	Screen size in square inches	Continuous
Tstat_Screen_Touchscreen	Touchscreen or Touchscreen plus buttons	Boolean

Preference Model Output

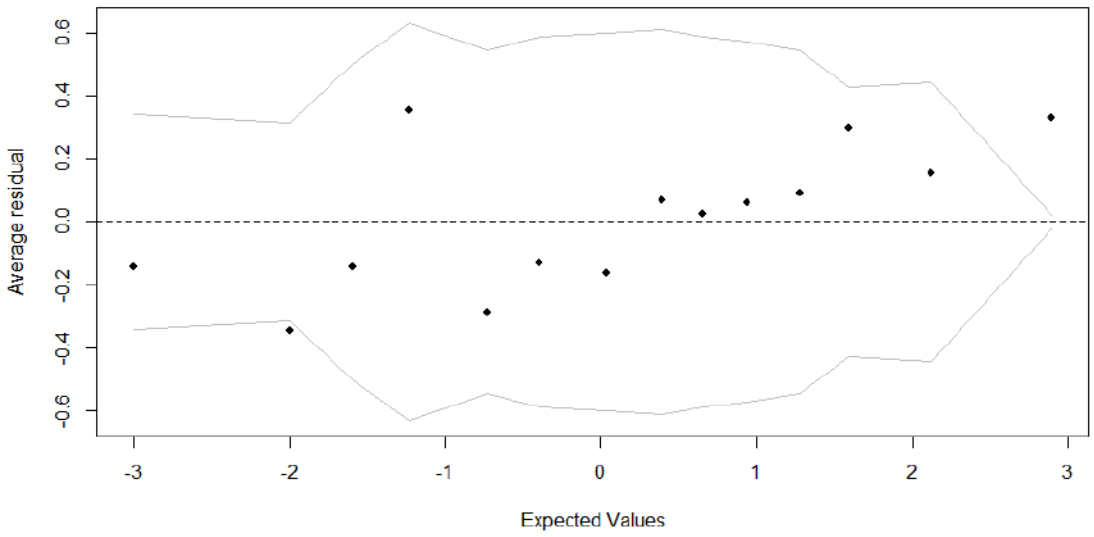
Figure 21. Preference model coefficients and significance

Preference	Estimate	Std.	Error	z-value	Pr(>|z|)
(Intercept)	-3.62	1.944	-1.861	0.063	.
Participant_<$50K	0.09	0.599	0.156	0.876	
Participant_$50-100K	-0.27	0.504	-0.540	0.589	
Participant_Age	0.02	0.015	1.226	0.220	
Participant_College	0.20	0.347	0.587	0.557	
Participant_Male	-0.08	0.354	-0.221	0.825	
Participant_Renter	-0.58	0.463	-1.261	0.207	
Participant_SmartphoneIQ	-0.06	0.166	-0.382	0.702	
Participant_ThermostatIQ	-0.16	0.259	-0.613	0.540	
Tstat_Access_Smartphone	-0.25	0.422	-0.589	0.556	
Tstat_Rated_Appearance	0.06	0.099	0.601	0.548	
Tstat_Rated_Ease.of.Use	0.18	0.096	1.916	0.055	.
Tstat_Rated_Feel.and.Sound	0.32	0.106	3.047	0.002	**
Tstat_Screen_Color.Display	1.20	0.455	2.638	0.008	**
Tstat_Screen_Size	0.14	0.153	0.949	0.342	
Tstat_Screen_Touchscreen	-0.55	0.799	-0.691	0.490	

Statistical Significance codes: ***: α=0.001; **: α=0.01; *: α=0.05

AIC: 254
Number of Fisher Scoring iterations: 5
Maximum VIF: 4.1

Figure 22. Preference model – binned residuals



Efficiency Model Output

Figure 23. Efficiency model – coefficients and significance

Efficiency	Estimate	Std.	Error	t-value	Pr(>|t|)
(Intercept)	0.538	0.118	4.557	0.000	***
Participant_<$50K	0.008	0.037	0.228	0.820	
Participant_$50-100K	0.006	0.032	0.180	0.857	
Participant_Age	-0.006	0.001	-6.224	0.000	***
Participant_College	0.011	0.022	0.499	0.618	
Participant_Male	-0.002	0.023	-0.076	0.939	
Participant_Renter	-0.089	0.029	-3.037	0.003	**
Participant_SmartphoneIQ	0.013	0.010	1.305	0.193	
Participant_ThermostatIQ	0.008	0.016	0.518	0.605	
Tstat_Access_Smartphone	-0.025	0.028	-0.904	0.367	
Tstat_Rated_Appearance	-0.012	0.006	-2.073	0.039	*
Tstat_Rated_Ease.of.Use	0.024	0.006	4.054	0.000	***
Tstat_Rated_Feel.and.Sound	0.010	0.006	1.520	0.130	
Tstat_Screen_Color.Display	0.038	0.027	1.393	0.165	
Tstat_Screen_Size	0.027	0.009	3.107	0.002	**
Tstat_Screen_Touchscreen	-0.112	0.044	-2.525	0.012	*

*Statistical Significance codes: ***: α=0.001; **: α=0.01; *: α=0.05*

Residual standard error: 0.1684 on 237 degrees of freedom
Multiple R-squared: 0.45
Adjusted R-squared: 0.41
F-statistic: 12.8 on 15 and 237 DF
p-value: < 2.2e-16
Maximum VIF: 4.2

FIGURE 24. EFFICIENCY MODEL – RESIDUAL PLOTS